ENGINEERING WORKS PRACTICE

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General Editor: E. MOLLOY

Advisory Editor: F. A. NORTON, C.B.E., M.Sc., M.I.Mech.E., F.R.Ae.S., M.Inst.T

VOLUME I

Basic Processes and Machines

Contributors:

A. OATES, A.M.I.P.E., A.M.I.E.I., M.Inst. Met.

E. D. BALL

B. LEVY

E. MOLLOY

W. S. WALKER M.Sc.(Tech.), Ph.D.

D. J. SMITH, O.B.E., M.I.Mech.E.

E. SIMONS

M. W. BOYCE

D. L. PERRY

G. W. WILLIAMSON, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.

E. G. LONGMAN

N. DAVIDSON, A.M.I.Mech.E.

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PREFACE

THE prosperity of Britain depends in no small measure on the excellence of her engineering products. There are upwards of one million people engaged in the various branches of the Engineering Industry.

Early in this century British-made engines, pumps, machine tools, textile machinery, locomotives and similar products were recognised throughout the world as being second to none. This was due to two facts, the skill of British steel-makers and the highly developed craftsmanship of British workmen.

In those early days of engineering, when Britain was the undoubted leader, engineering products were made with three main objects in view:

Efficiency
Reliability
Durability.

Cheapness of manufacture was a secondary consideration.

The idea of mass production, to achieve low manufacturing costs, was developed in the United States in the first decade of the present century. The 1914–18 War made the introduction of mass-production methods imperative in this country for the rapid production of arms.

Since 1919 mass or quantity production has become more and more important in this country, as it is only by adopting modern methods of production that we can hope to compete in world markets with the engineering products of America.

Paradoxical as it may seem, the successful application of quantity production methods requires that in the industry there must be a large body of highly skilled craftsmen capable of working to much finer limits of accuracy than was the case when all component parts of engineering products were fitted by hand.

Quantity production, therefore, instead of reducing the need for highly trained craftsmen has created a much keener demand for men highly skilled in all engineering workshop processes and machines.

It is these men who form the backbone of the Engineering Industry and who make it possible for large numbers of less highly skilled operatives to earn much higher wages than they could ever hope to do under previous conditions.

In engineering, as in most other walks of life, there are two very sharply divided groups of people:

(*a*) Those who have drifted into the industry as a means of making a livelihood and who are content to earn the regulation "rate for the job," doing a fair day's work for a fair day's pay, and neither wishing nor expecting to rise to positions of greater responsibility.

(*b*) Those who have taken up engineering because they feel that it is a worth-while job—the only job in which they would ever be satisfied, and one affording scope for initiative and offering a wonderful field for progress.

Fortunately for this country the proportion of men in the (*a*) group in the Engineering Industry is comparatively small. Most men in this great industry, whether they are engaged in the maintenance of power plant, operating an automatic screw machine, a drop hammer, a hydraulic press, or in the toolroom or the drawing office, or on the test-bed, or even on the assembly line of a car factory, have entered this industry because they were drawn towards engineering and believe that they can make a successful career in this field. It is to help these men to realise their youthful ambitions that the present work has been prepared.

The plan of the work may be described very briefly as follows:

Volume I deals with the fundamental workshop processes and machines, ranging from pattern-making to wiredrawing.

Volume II deals with processes which, though fundamental, are of more recent growth. In this volume, for instance, considerable space has been devoted to the various specialised techniques which have been developed in gas and electric welding and oxygen cutting, the use of mechanical and hydraulic presses, the various processes used in treating engineering materials, such as degreasing, descaling and protective processes, the new technique of powder metallurgy and the properties of the chief materials used in engineering.

The main theme of Volume III is Production Engineering—both "quality" production and "quantity" production. In order to obtain the latest information many visits have been made to some of the largest engineering works in the country and many hundreds of photographs have been specially taken to illustrate the most up-to-date methods now in use in the more important branches of engineering production, e.g. automobile manufacture, shipbuilding, engine manufacture, aircraft manufacture, and the manufacture of locomotives.

This volume will be found of the very greatest interest to those men who aspire to obtain responsible positions in the large engineering works which have adopted, or will adopt in the near future, quantity production methods.

Volume III also contains an article on the important subject of *Packing Engineering Goods for the Export Market.*

Manufacturers exporting goods, in some cases for the first time, are faced with numerous problems relating to correct methods of packing and dispatch. A wealth of expert information is available to suit their respective needs, and it cannot be too strongly emphasised that they should give this matter most careful attention. Any neglect on their part might mean the loss of all the care and skill which has gone into fine production work, and this would eventually have a serious effect on the country's export drive.

The article describes and illustrates up-to-date methods of packing widely differing types of products so as to withstand the common shipping hazards, such as rough handling during voyage and unloading, damage by friction, and deterioration through climatic variations. Notes are also given on correct

identification methods and consignment procedure, and the article concludes with a useful list of Packaging Institutions and Research Laboratories.

Whilst the driver of a locomotive or a steam turbine in a power station, or a Diesel electric generator, must obviously have an interest in prime movers and their auxiliaries, such as boiler-house plant, pumps and condensers, the engineer who is engaged on the production side in the industry should also be acquainted with the methods by which the power to drive his factory is applied to the machines where it is required.

Works engineers must also be capable of installing or supervising the installation of the various types of machinery which they have manufactured.

Volume IV, the concluding volume of this work, deals with the installation, operation, and maintenance of the chief types of engineering plant and equipment. Emphasis has been placed upon those aspects of the work which are likely to be of the widest utility.

F. A. NORTON, C.B.E., M.Sc., M.I.Mech.E.
E. MOLLOY.

CONTENTS OF VOLUME I

CHIEF CONTRIBUTORS

A. E. W — A. E. WILLIAMS, Ph.D., F.C.S. Served in First World War in the Special Brigade branch, Royal Engineers. Since then has been engaged as a Technical Consultant by several well-known companies, and latterly. working on his own account, as an Industrial Consultant. Contributor to prominent British engineering journals.

A. L. — A. LITTLEWOOD, A.M.I.Mech.E. Received his technical education at the South-east Essex Technical College. Was then engaged at the works of one of the major motor-vehicle manufacturers, and was subsequently employed in the Factory Planning Department of a mass-production organisation. Part-time Lecturer and, latterly, has specialised on plant layout work in process industries.

B. L. — B. LEVY. Member of the London Branch Council of the Institute of British Foundrymen, and the Technical Committee, London Branch, Engineering and Allied Employers' Association. Has been engaged for over thirty years in pattern-making, and is the founder of the well-known pattern-making business of B. Levy & Co.

D. J. S. — D. J. SMITH (Lt.-Col.), O.B.E., M.I.Mech.E. Educated at Charterhouse. Apprenticed to Maudsley, Sons, and Field. Elected Council Member of Institution of Automobile Engineers, 1907. Member of Horse-power Formulæ Committee 1908, President 1922. Member of Empire Motor Fuel Committee. Manufacturer of high-pressure steam boilers, light railway locomotives, and railcars. Patentee and manufacturer of portable and stationary gas producers, distillers', and brewery machinery. Contributor to many technical works and publications.

D. L. P. — D. L. PERRY. Sales Manager of B. & S. Massey, Ltd. Has had over thirty-five years' practical experience in the manufacture of forging and drop-forging plant. Recently spent some months in U.S.A. and Canada studying American methods in the drop-forging industry. Has contributed articles on the subject to technical journals.

E. D. B. — E. D. BALL. Received his technical training Portsmouth Technical College. Apprenticed to Rolls-Royce, Ltd., becoming leading tool designer. Tool and production specialist contributor for fifteen years *The Automobile Engineer*. Founder Member Institution of Production Engineers, serving five years as Hon. Secretary. European Representative Hutto Engineering Co., Detroit. Later associated with George Alexander Machinery, Ltd., and Speed Tools, Ltd., as designer and patentee of tool equipment, especially quick-acting clamps and A-B honing tools.

E. D. E. — E. D. EVANS, M.S.W.I.E., etc. Educated Rhondda Grammar School 1911–1916. South Wales and Monmouthshire School of Mines 1919–1923. Flying Officer R.N.A.S. and R.A.F., 1917–1919. Turbine Construction Department, The British Thomson-Houston Co., Ltd., 1923–1941, in charge Operation 1929–1941. Turbine Engineering Department, in charge Operation present day.

E. G. L. E. G. LONGMAN. Received his training at Weymouth and the mid-Essex Technical College. Whitworth Exhibition, 1921. Was apprenticed to Vickers Armstrong, Ltd. Joined the staff of The Hoffmann Manufacturing Co. in 1922, working on bearing design, application, and research, and now Chief Designer of that company.

E. G. W. E. G. WEST, Ph.D., F.I.M., F.R.S.A. Graduated with honours in Metallurgy at the University of Birmingham, and was awarded degree of Ph.D., 1932. Joined the British Non-Ferrous Metals Research Association as a senior investigator, 1938. In 1941 he was appointed first Manager of the newly formed Wrought Light Alloys Development Association. This Association was taken over in 1945 by the Aluminium Development Association, when Dr. West became Technical Director, which position he still holds.

E. M. E. MOLLOY. General Editor, Technical Books Department, George Newnes, Ltd. Trained Royal Technical College, Salford. Obtained King's Prize in Applied Mechanics in 1911. After practical experience with Lea Recorder Co., Ltd., and United Brassfounders & Engineers, Ltd., joined editorial staff of *Electrical Engineering*. Assistant Examiner Inventions Department, Ministry of Munitions, 1917–19. In 1919 joined Sir Isaac Pitman & Sons, Ltd., and in 1924 was appointed Technical Editor. Joined staff of George Newnes, Ltd., in 1929. Has specialised in the editing of technical publications.

E. P. E. PULL, M.I.Mech.E., M.I.Mar.E. Received his technical training with a firm manufacturing gas engines and steam plant, and at the Goldsmith College, New Cross. Passed Assistant Engineers Examination. Served in the Royal Navy, and holds an extra first-class Engineer's Certificate. Chief Instructor at the Poplar School of Engineering and Navigation, and, latterly, has worked as a consultant in steam-generating plant. Author of many successful technical books.

E. S. E. SIMONS. Born 1896 at Birmingham. Joined Edgar Allen & Co., Ltd., Sheffield, 1911. Passed through Foundry and Export Departments. Appointed Publicity Manager, 1923. Editor of *Edgar Allen News*. Has visited works in France, Switzerland, Russia, Austria, Yugoslavia, Bulgaria, Turkey, Rumania, Hungary, the United States, etc. Author of some twenty books on technical subjects, either singly or in collaboration. Vice-Chairman Northern Branch of A.S.L.I.B. During the war wrote much propaganda for the M.O.I. and the British Council.

E. S. S. E. SEYMOUR SEMPER, M.I.Mech.E. Mr. Semper entered the welding industry on leaving Sheffield University in 1922. His experience includes arc and resistance welding, as well as gas welding, although he has latterly specialised in oxygen cutting, being the author of a book on the subject. During the war he was with the Ministry of Supply in an advisory capacity. He is now a Director of Hancock & Co. (Engineers), Ltd. He was a founder member of the Institute of Welding, and at present is President of the South London Branch, Member of Council and General Purposes Committee, and Chairman of the Education Committee.

F. A. N. F. A. NORTON (Group-Captain), C.B.E., Royal Air Force (retd.), M.Sc., M.I.Mech.E., F.R.Ae.S., M.Inst.T. Pupil of Peter Brotherhood, Ltd., Peterborough. Caius College, Cambridge, Degree-Master of Science. Research and Development Mechanical Transport and Aircraft, Air Ministry and Ministry of Aircraft Production. Chief Technical

Officer, Maintenance Command U.K., Mediterranean and India Commands Royal Air Force. Created Companion of the Order of the British Empire, 1947.

G. I. — G. IRVING. Has been engaged in mass-production planning for over twenty-two years. Lecturer in Industrial Administration to candidates for Associateship of Institution of Mechanical Engineers. Latterly, tutor for Foremen's Training Schemes.

G. R. W. — G. RIDLEY WATSON, B.Sc., M.I.N.A., M.I.Mar.E. Trained in all inside and outside departments of Sir W. G. Armstrong, Whitworth & Co.'s Elswick Shipyard and Armstrong Naval Yard, Walker-on-Tyne. Attended Armstrong College (King's College), obtaining B.Sc., degree Durham University in Naval Architecture. Assistant Shipyard Manager at Armstrong Naval Yard, supervising construction all classes of warships, high-class passenger and cargo ships. Upon merger of Vickers and Armstrongs, transferred to Barrow-in-Furness. 1929, appointed Armstrong Whitworth shipbuilding representative in London, Joined Mr. Henry Robb, shipbuilder, of Leith, 1934, opening London office for Henry Robb, Ltd.; appointed Director, 1935.

G. W. W. — G. W. WILLIAMSON, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S. Is the author, or joint editor, of *A Primer of Flying* (Pitman); *The Flight Mechanic's Handbook*; *Aircraft Engineer's "A" Licence*, and *Aircraft Engineer's "C" Licence* (all Newnes); *Motor Vehicles of To-day*; *Materials Handling Manual*; *Aircraft Development and Production* and *Aircraft Maintenance Manual* (all Paul Elek); *Electro-Industry* (Hindlip).

H. G. — H. GREAVES. Mr. Greaves has been continuously occupied with the drawing office and research work for over thirty years, and is now Chief Draughtsman at John Thompson (Wolverhampton), Ltd. Amongst other activities, he gives lectures to the engineering apprentices at the above firm in connection with the design of shell-type boilers.

H. M. D. — H. M. DERRICK (Mrs.), A.M.I.Chem.E. Mrs. Derrick is twenty-nine years old. She trained as a chemist, but became interested in chemical engineering, and in 1943 became the first woman and, incidentally, the youngest student, to pass the Associate Membership Examination of the Institution of Chemical Engineers. On her marriage she moved to Stroud, and joined the technical sales staff of T. H. & J. Daniels, Ltd., who manufacture plant for the plastics industry. She has a broad knowledge of plastics, both from the chemical and engineering sides, and has lectured and broadcast on the subject.

H. W. G. — H. W. GREENWOOD. Received his technical training at the Liverpool School of Science and Technology. Spent twelve years in a metallurgical laboratory in Liverpool, four years in Spain in charge of ore-concentrating and magnetic-separating plant. Returned to England shortly before the First World War. Joined the late A. R. Davies, Chemical Engineer, as Manager of a mill producing special papers for the photographic industry, the next twenty years in that industry, and in 1938 joined Dr. W. D. Jones, the pioneer in Powder Metallurgy, and has been associated with him ever since. Is an original Member of the Institute of Metals.

J. A. O. — J. A. Oates, A.M.I.P.E., A.M.I.E.I., M.Inst.Met., etc. Apprentice trained, and has a wide practical experience of all branches of machine shop and other engineering processes. Was for several years an Associate Editor, and now is a contributor on technical subjects to a variety of British and Overseas journals. Author of Newnes' *Aircraft Production; Turret Lathe Setter's Pocket Book*, and other publications.

J. C. — J. Chamberlain. Received his technical education at Derby Technical College. Entered the services of Aiton & Co., Derby, in 1914, and trained in pipework engineering in all aspects at home and abroad. Appointed Chief Draughtsman in 1930, held this appointment until January 1947, when he was promoted to the position of Chief Engineer.

J. F. P. — J. F. Paterson. Thirty-eight years of age. Received his technical education at the Royal Technical College, Glasgow, in Mechanical Engineering. Engaged in automobile engineering since 1933, and in the Metrology Division of a large concern manufacturing automobiles by mass-production methods. Part-time lecturer in Mechanical Engineering course with Essex Education Committee.

J. G. F. — J. G. Frith, M.I.Mech.E. Assistant Chief Engineer in charge of hydraulic machinery design, Davy and United Engineering Co., Ltd., Sheffield. Holder of the Associateship in Engineering, Sheffield University. Member of the Iron and Steel Institute. Past Chairman of Development Committee, National Trades Technical Societies.

J. H. S. Y. — J. H. S. Young. Has been engaged for the past twenty years in and around collieries, and has made an extensive study of mining equipment for both underground and surface use. At present employed by the Consolidated Pneumatic Tool Co. as Mining Representative for the North of England. In addition to service in this country has operated abroad on behalf of British Jeffrey Diamond, Ltd., of Wakefield.

J. R. F. — J. R. Fawcett, B.Sc.(Hons.), A.M.I.Mech.E. Received his engineering training at Birmingham Technical College and the Austin Motor Co., Ltd. For the last twelve years Chief Engineer with one of the leading instrument companies. Has specialised on the design and production of small mechanisms, and written several books and many articles on instruments and light-engineering technique.

J. W. — Mr. J. Woolman was educated at Sheffield University, where he graduated with an Honours Degree in Physics in 1914 and Master of Science in 1915. After service in the First World War and a short period in 1919 and 1920 as Demonstrator in Physics at Sheffield University, he joined the Brown-Firth Research Laboratories as a Physicist. He became Head of the Laboratories in 1942, and was made a Local Director of Messrs. Thos. Firth and John Brown, Ltd., in 1946. He is a member of the Ingot Moulds Committee of B.I.S.R.A. and Chairman of the Stresses in Moulds Panel.

J. W. T. — J. W. Tomlinson. Technical author of Rolls-Royce, Ltd., Technical Sales Department, Derby. Joined the firm as an apprentice during First World War. Studied at the Derby Technical College, and has been associated with the production and repair of automobile and aero engines for the past thirty years. He has contributed many articles to aeronautical and engineering journals.

L. G. A. L. L. G. A. Leonard. Director and General Manager of The Dowson & Mason Gas Plant Co., Ltd. One-time Chief Designer and Assistant General Manager of British Furnaces, Ltd., Chesterfield. Member of the Institute of Fuel.

L. H. B. L. H. Broadbent, who contributes the article on *Weighbridges for Heavy Loads*, is well-informed on the subject by virtue of his forty-two years of service with W. & T. Avery, Ltd., the well-known makers of weighing, counting, and testing machines. For more than half of his period of service he has been the company's Publicity Manager, and as such has been responsible for the production of literature dealing with the company's products.

L. J. L. Johnstone, A.M.I.Mech.E. Has been with the Austin Motor Co., Ltd., since 1928. After twelve years in the Tool Designs Office as a Designer and Section Leader on special machine design, he joined the Planning Department as Planning Engineer for certain war contracts. In 1945 he was appointed Chief Planning Engineer for the Engine Factory, and since 1948 has been a Project Planning Engineer.

M. W. B. M. W. Boyce, the contributor on *Portable Power Tools*, has, for the past twelve years, handled Sales Promotion and Advertising for Black & Decker, Ltd. Most of the twenty-five years he has had in advertising circles have been spent closely tied up with the manufacture and merchandising of electrical products, both for industry and the home consumer.

N. D. N. Davidson, A.M.I.Mech.E.; Assoc.M.C.T. Born 1903, Manchester. Educated Manchester College of Technology, taking the Engineering Diploma. Special Prizewinner, Institute of Mechanical Engineers. Served apprenticeship in wire concern, becoming Works Superintendent. Now Technical Director of Sir James Farmer Norton & Co., Salford, and General Manager and Director of Associate Company, Wiredrawing Dies (Manchester), Ltd. Served on Diamond Die Advisory Committee for Diamond Dies.

N. R. C. N. R. Chandler, M.I.Mech.E., M.S.A.E. Technical training at Birmingham University, 1899–1902. Apprenticeship, works and drawing office, with Bumsted & Chandler, Ltd., where he later had charge of Steam Engine and Electrical Testing and Motor-car Repair Department. Early in 1911 joined Rolls-Royce, Ltd., at Derby, as Technical Chief of Repair Department. Manager for Rolls-Royce in India from 1929 to 1935; on return joined the Chassis Experimental and Development Department at Derby. During both wars, when no cars were made, was on Aero-engine technical production staff. Retired, 1949.

R. S. R. Shilton, B.Sc.(Eng.)(Hons.), A.M.I.Mech.E., A.M.I.P.E., A.M.I.A.A. Served apprenticeship in machine-tool making. Subsequent experience in commercial motor vehicles, boilers and heating plant, woodworking machinery, jigs and tools. Became full-time Technical College Instructor in Production Engineering, Lecturer in Mechanical and Civil Engineering, followed by experience as Industrial Management Consultant, and Lecturer in Management subjects, Chief Engineer and University Lecturer.

T. B. S. T. B. Sansom. Received his technical education at Nottingham University and served an apprenticeship at Ransom & Marles Bearing Co., Ltd., Newark-on-Trent. After qualifying he studied administrative and

production methods as applied to bearing manufacture. Served in the Second World War as a Research Engineer in the Royal Naval Scientific Service, undertaking work in connection with mines and torpedoes. At the conclusion of the war joined Bruch Peebles & Co., Ltd., as an Electrical Engineer responsible for electrification contracts involving Glass Bulb and Steel Tank Rectifier Equipments. In 1949 he joined the staff of J. D. Crozier & Partners, Power Plant and Fuel Advisory Engineers, as a Consulting Engineer.

T. D. W. T. D. WALSHAW, B.Sc.(Eng.), D.L.C.(Hons.), A.M.I.Mech.E., A.M.I.P.E., Foreign Member of the Society of Automotive Engineers (U.S.A.). Received his engineering education at Loughborough Engineering College, where he obtained a Diploma in Mechanical Engineering and an External Degree from the University of London. In 1934 he joined the staff of the National Gas and Oil Engine Co., Ltd., first as Engine Tester and Erector, later as Draughtsman in the Large Engine Department, and finally as Assistant to Mr. J. Jones, then Chief Engineer. Whilst at National's he was intimately connected with the development of both the dual-fuel engine and the high-compression gas engine. In 1934 he took up an appointment as senior lecturer in the Department of Mechanical Engineering, Loughborough College, his principal subjects being Thermodynamics and Engineering Design. Since 1948 he has been lecturer in Mechanical Engineering at Liverpool University, specialising in Internal Combustion Engines. Author of *Diesel Engine Design* and numerous articles on Internal Combustion Engineering. His main hobby is the design and manufacture of small steam locomotives.

W. E. S. W. E. STANLEY, A.C.W.A. The writer of the article on *Costing* is a qualified Cost and Works Accountant, and in addition has been actively engaged in Production Planning in its many aspects since 1933. He has also contributed to foremen's training schemes in a large concern employing 16,000 people, lecturing on Organisation and Management as well as Costing.

W. H. K. W. H. KENNEDY. Son of William Kennedy, inventor and patentee of the original "Kennedy" Benders. Has specialised in cold bending for twenty-eight years; recognised to-day as one of the principal authorities in Great Britain on cold bending; consulted during the war on bending problems for Operation F.I.D.O., and many special aircraft constructions involving bending of tubes and sections. Author of *Bending by Machine* and other works on this subject.

W. L. W. LAMB, M.I.Mar.E., M.Inst.F. Educated at the Rutherford Technical College, Newcastle-on-Tyne. Apprenticed to a Marine Engineering concern followed by service in the Royal Engineers, 1914–18. Later Engineer Officer in the Royal Merchant Navy. He has held positions ashore as Shift Engineer, Power-plant Superintendent, Steam Production Manager, and, finally, Technical Officer in the Civil Service. Author of technical publications on steam plant and lecturer on Boiler-house Practice, Nottingham and District Technical College.

W. P. H. W. P. HARRIS. Manager of Solex (Gauges), Ltd., formerly on the staff of the Machine Control as a Technical Officer in the Directorate of Gauges and Measuring Instruments (production) M.T.C. 5 C. Before taking this appointment he was with the Ministry of Labour. Previous to this, Mr. Harris was the Chief Inspector (Gauges) of the

southern factory working under the Admiralty, producing 20-mm. guns. He was an apprentice engineer in the motor industry before taking up work as an A.I.D. approved Chief Inspector.

W. S. W. W. S. WALKER, M.Sc.(Tech.), Ph.D., Metallurgist. Technical Director, Round Oak Steel Works, Brierley Hill, Staffordshire. In 1933 graduated B.Sc.(Tech.) First Class Honours, University of Manchester; 1934, M.Sc.(Tech.); 1935, awarded Carnegie Scholarship by the Iron and Steel Institute; 1936, Demonstrator in Metallurgy in the College of Technology, Manchester, and in the University of Manchester; 1937–9, Vitkovice Iron and Steel Corporation, Czechoslovakia; 1939–41, Brown-Firth Research Laboratories, Sheffield; 1941–5, Production Manager, Light Alloy Department, Firth-Brown; 1946, Ph.D.; 1945–7, Development Engineer, Firth-Brown. 1947–50, Technical Engineer, Firth-Brown. 1950, Technical Director, Round Oak Steel Works.

W. T. P.-W. W. T. PELL-WALPOLE, Ph.D. Graduated at Birmingham University in 1933. From 1933 to 1938 Post-Graduate research at Birmingham University for Tin Research Institute on Tin Alloys; 1933–4, Staffordshire County Major Scholar; 1934–6, Bowen Scholar in Metallurgy; 1936, awarded degree of Ph.D. and Thomas Turner Bronze Medal for research work on constitution and properties of tin-base alloys; 1938–41, Senior Metallurgist, Tin Research Institute, continuing researches, mainly on tin-base bearing metals; 1941–5, Chief Metallurgist, Tin Research Institute, seconded to Metallurgy Department, Birmingham University, for researches on melting, casting, and working of bronze; 1945, elected to Gibbins Research Fellowship, Birmingham University; 1947, I.C.I. Research Fellow, Metallurgy Department, Birmingham University, continuing researches and lecturing on copper-base alloys. Author or joint-author of several papers on copper-base and tin-base alloys in the *Institute of Metals* and other journals.

ENGINEERING WORKS PRACTICE

INTRODUCTION

WHY is engineering so fascinating?

A small boy who is asked what he would like to be when he grows up almost invariably selects as his first choice "an engine-driver." Millions of small boys who have expressed this wish have eventually become lawyers, solicitors, bank clerks, stockbrokers, artists, tinkers, tailors, soldiers or sailors. Only a small but very select proportion of them carry out their first ambition.

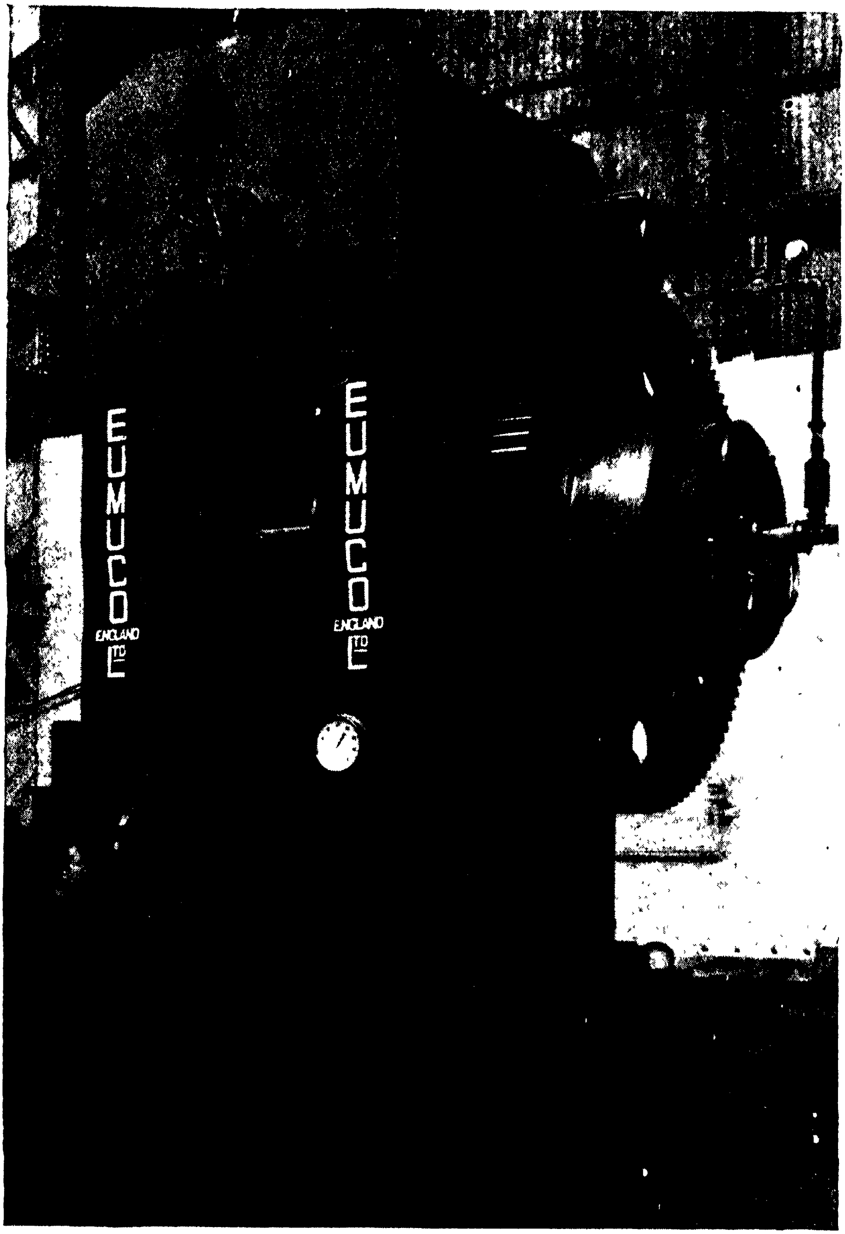
Although it is well over a hundred years since George Stephenson built his first locomotive, the career of the engine-driver still seems to the youthful mind one of the most attractive forms of human activity. This is probably because, in driving a locomotive, the manipulation of one or two handles and levers produces astonishing results. A train weighing many hundreds of tons can be moved at speeds up to eighty miles an hour or more, and all the time it remains fully under the control of its driver.

The fascination of engineering is due to the immense power which an engineer is able to control and direct. *Engineering is, in fact, the art of controlling the forces of Nature.*

By pressing buttons and moving levers engineers are able to cut, mould and shape metal with far less physical exertion than that used by the blacksmith in shoeing a horse. The blacksmith was, incidentally, the original hand-worker in metals. To-day, the engineer is not called upon to use great physical exertion except in certain heavy engineering processes such as metal founding; but he has to use his brains, and has also to exercise a very considerable degree of craftsmanship in working to limits of accuracy which were far beyond the capability of the old blacksmiths.

Teamwork in Engineering

The first requirement for any engineering product is good design. Without this, the work of the most highly skilled craftsman will not ensure a perfect product. Conversely, even with a good design, poor craftsmanship will yield only a second-rate product. Good production planning is essential in order that the product may be manufactured in the right quantities at a competitive price. Designers, production planners, and craftsmen form a team, and the



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By pressing buttons and moving levers engineers are able to forge, cut and shape metal with far less physical exertion than that used by the blacksmith in shoeing a horse.

work of each member of the team affects vitally the success of the teamwork. Good teamwork amongst engineers is a factor which has contributed enormously to the success of this great industry during the past years.

ENGINEERING WORKS PRACTICE has been planned having in view the latest developments in all branches of engineering. The words "Engineering Works Practice" in the title have been chosen deliberately to indicate that the scope is far wider than would have been implied by the words "Workshop Practice." It is designed to be of use to engineers of all grades, and whatever the technical skill or academic knowledge of the reader, he will find a wealth of useful information in the pages which follow.

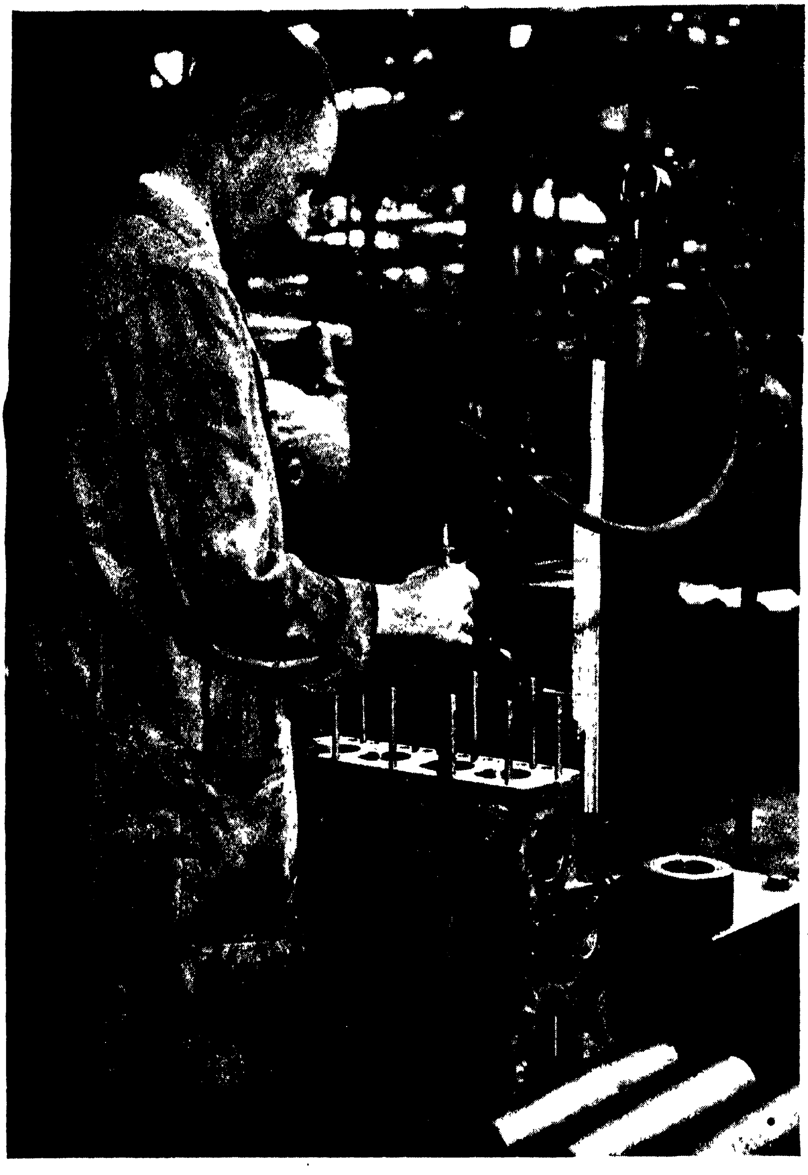
The term "engineer" is a wide one. It may be used to describe a successful consultant or designer earning two, three, or five thousand pounds a year, or a man responsible for running a power plant in a small works or factory and drawing from five to ten pounds as his weekly wage. Can it be reasonable to describe both these widely differing types of workers as engineers, and if so, why should there be this great difference in the rewards given by the community to these two individuals, both of whom are engineers?

It would not be fair to say that in the first case mentioned the individual concerned is living on the work of other people. In actual fact his work not only provides him with a comfortable livelihood, but provides work for, it may be, thousands of other less highly skilled engineering workers. For example, the engineer-consultant who can produce the specifications for a new generating station is the agent who provides employment for the thousands of men who will be necessary to bring that station into actual being.

The designer who can produce plans for a new jet engine or a gas turbine may be instrumental in finding employment for several thousands of engineers of all grades who will be required to prepare detailed drawings, make patterns, produce castings, manufacture special presses, prepare production schedules, design special tools and jigs, set complicated machine tools for repetition work, prepare limit gauges for the various component parts of the engine, and test the finished job.

After the completed engines or turbines have successfully passed their bench tests, they must be installed in the aircraft or in the generating station for which they are intended. Here again the services of hundreds of installation engineers will be required. After a specified number of hours' running, these engines will need to be taken down and thoroughly inspected for wear, which may involve the replacement of certain parts. For this work many maintenance engineers are required.

The above examples show in a striking manner how the activities of one man, who has reached a high stage of efficiency in his engineering knowledge, can be instrumental in providing the means of livelihood for many thousands of his fellow engineers. Exactly the same conditions to a lesser degree exist in the case of engineers who have taken the trouble to equip themselves with technical knowledge which extends beyond the bare requirements of the one small branch of engineering work in which they are already reasonably adept.



FINAL INSPECTION OF CYLINDER BORES, USING A SOLEX AIR GAUGE

The final quality of an engineering product depends on the thoroughness of the Inspection Department. To maintain a high standard it is essential that the Department is under the control of the Chief Engineer.

Now let us look at the other extreme. A young man has entered an engineering works, and, in the course of two or three years, has acquired some facility in, let us say, operating a capstan lathe. As he is paid on piece-work and has become reasonably expert, he is able to earn sufficient to keep himself in moderate comfort. He cannot see any reason why he should take the trouble to acquire knowledge of other branches of engineering. He is content to remain one of a crowd.

Such a man remains always at the mercy of circumstances. In times of prosperity in the engineering industry he is able to make sufficient to live upon. When hard times come along and his firm is obliged to cut down expenses, he will certainly be amongst the first to receive notice. ENGINEERING WORKS PRACTICE has not been written for engineers who have planned their lives within these narrow confines.

There is Room for You Higher Up

ENGINEERING WORKS PRACTICE has been written to assist men who are prepared to take the trouble to equip themselves with that broad basis of engineering knowledge which is necessary for all who wish to hold positions of responsibility in the field of engineering. More than fifty contributors, each one a specialist in some particular branch of the subject, have given here the results of their lifetime's experience.

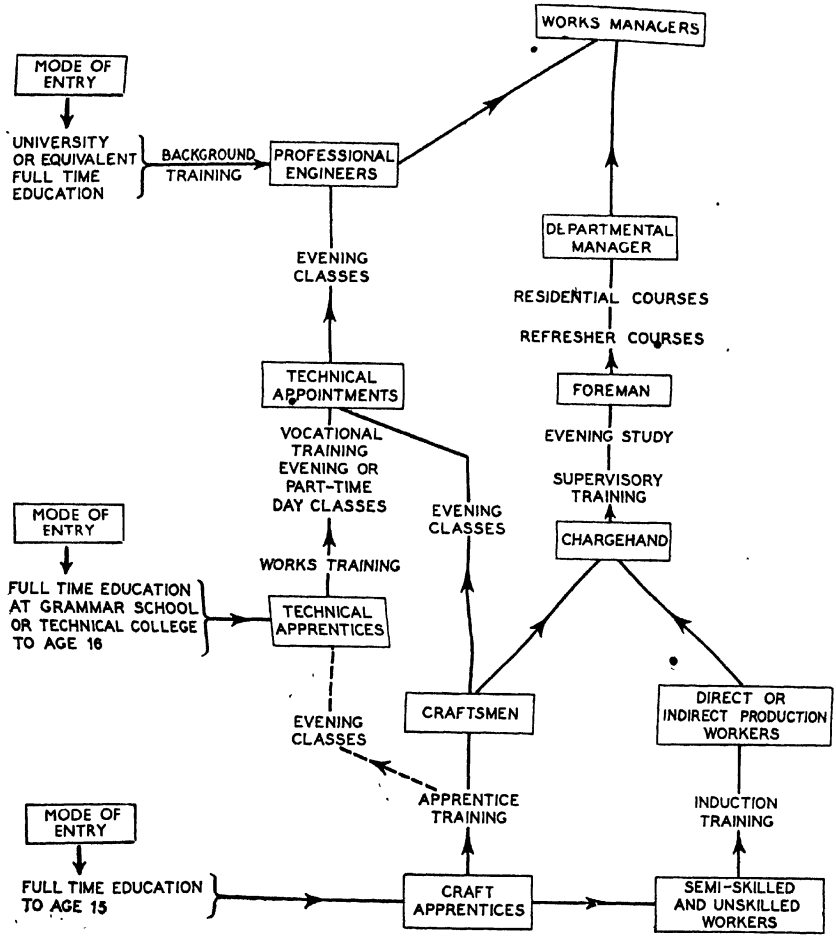
No one can become an engineer merely by reading about engineering; but, on the other hand, there is no man alive who can find the time to obtain practical experience in every separate branch of engineering. It is safe to say that every reader of these pages is already well on the way to becoming an expert in one or other branch. It may be as a fitter, turner, toolsetter, a boiler-house engineer, a maintenance engineer, a welder, a pattern-maker, an engine tester, skilled draughtsman, or production engineer.

By adding to his existing specialised knowledge the wealth of information which will be found in the pages of this work, every reader should be able to qualify himself for a position of greater responsibility, and it cannot be too strongly emphasised that in so doing he is acting, not only in his own interests, but also in the interests of the community at large.

There are always more jobs available entailing real responsibility than there are men to fill them, and when these positions have perforce to be given to men who are not fully qualified to hold them, trouble, inefficiency, and muddle result.

The illustration on page 6 shows the three methods of entrance into the engineering industry. From this it will be seen that in a large engineering works, high executive positions, such as Departmental Manager or Works Manager, can be attained by any keen young man even though he may not have had the advantages of a University or Technical College training—*provided he is prepared to study in his spare time.* ENGINEERING WORKS PRACTICE provides an excellent foundation for this study.

Through the co-operation of many of the largest engineering firms, we have



THREE WAYS OF ENTERING THE ENGINEERING INDUSTRY

The above chart illustrates graphically the opportunities which engineering offers to a young man whether he enters the industry at the age of 15 after completing primary education, or at the age of 16–17 after Grammar School or Technical College training, or after having taken an engineering degree at a university.

Youths entering at the lower age have to climb more steps to reach higher positions, but to balance this they have several years' start of those men who enter after having taken a full college training.

been able to secure hundreds of photographs illustrating up-to-date methods which are being employed in the various branches of the engineering industry to-day. We are also indebted to a large number of engineering firms who have kindly allowed members of their staff to contribute important sections of the

work and who have also assisted us by supplying information and data to be incorporated in the work.

In this connection we would specially mention the following:

A.E.C., Ltd.
A-I Electric Welding Machines, Ltd.
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Leeds Water Meter Co., Ltd.
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Scottish Machine Tool Corporation, Ltd.
Shaw, John, & Sons (Salford), Ltd.
Sheepbridge Engineering, Ltd.
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Simon-Carves, Ltd.
Sintered Products, Ltd.
Smith, Hugh, & Co. (Possil), Ltd.
Smiths Aircraft Instruments, Ltd.
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Solex (Gauges), Ltd.
Stockton Chemical Engineers & Riley Boilers, Ltd.
Sturtevant Engineering Co., Ltd.
Suffolk Iron Foundry (1920), Ltd.
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Taylor, Charles (Birmingham), Ltd.
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Weir, G. & J., Ltd.
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White, J. Samuel, & Co., Ltd.
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Whites-Nunan, Ltd.
Wickman, A. C., Ltd.
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As a result of this generous co-operation, we have been able to bring together a unique collection of up-to-date information on all the main aspects of engineering. It is hoped that engineers of all grades will avail themselves of this opportunity of extending their knowledge of this great industry, and thus fit themselves to occupy positions of increased responsibility. Not only will this result in their receiving higher financial rewards for their labours, but it will meet a pressing need of the present day.

E. M.

BASIC PROCESSES AND MACHINES

HOW TO READ A BLUE PRINT

THERE are two systems used for preparing workshop drawings, one known as the First Angle Orthographic Projection, and the second, referred to as Third Angle Projection, largely used in America, and finding increasing applications in this country.

First Angle System

Fig. 1 (*a*) shows a small casting situated in the angle formed by a vertical and horizontal plane. By looking on the top of the casting, a plan view can be projected on to the horizontal plane; and by looking at the front, the front view or elevation can be projected on to the vertical plane. If this pair of planes is then opened out flat, as shown in Fig. 1 (*b*), the elevation will appear at the top and the plan directly underneath it.

Fig. 2 (*a*) and (*b*) show the same principle applied to obtain plan, elevation, and end view. Note that the end view is the view seen when looking at the end farthest away from the end view.

Sectioning

So far we have assumed that the article shown can be fully represented by views of its exterior. The occasion frequently arises, however, when some clear indication of the interior of the article becomes necessary. In this case, sectional views are used. These show the component as though it were cut in two in the desired plane. In such cases, the entire area representing the cut is covered with light parallel lines which are usually arranged to run at 45° to the main contour lines of the section.

Figs. 3 and 4 illustrate the principle of sectioning. Fig. 3 (*a*) shows a metal fitting cut by an imaginary vertical plane. If the front half were removed, then the interior of the fitting could be clearly seen.

Fig. 4 shows two alternative methods of indicating the shapes of hidden parts. On the left of this illustration are shown a plan and elevation, on which dotted lines are used to show the bolt holes and the interior shape of the fitting. On the right of Fig. 4 will be seen a plan and sectional elevation of the same fitting.

The Auxiliary Plane

In order to give complete information regarding the internal or external shape and dimensions of components, it is sometimes necessary to take a view projected on a plane other than the vertical or horizontal plane. The method of projecting such a view is clearly illustrated in Fig. 5 (*a*) and (*b*).

FIRST ANGLE PROJECTION

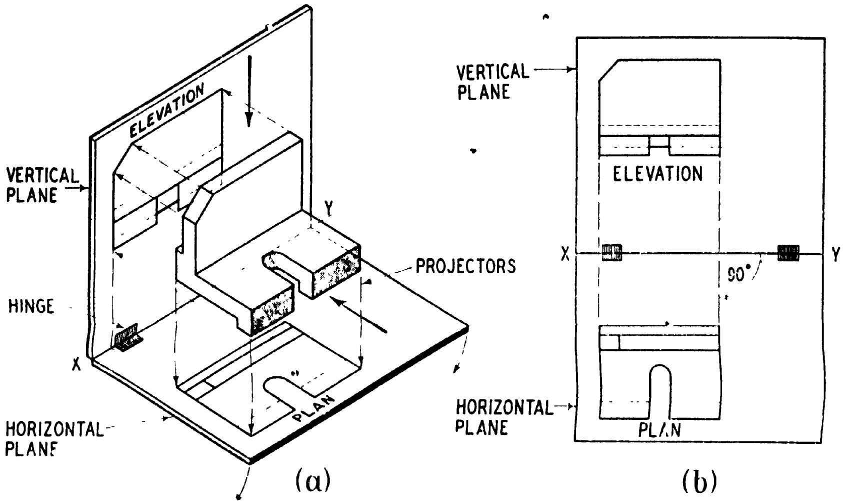


FIG. 1.—ILLUSTRATING FIRST ANGLE PROJECTION OF ELEVATION AND PLAN VIEW

Showing a small casting situated in the angle formed by a vertical and horizontal plane. By looking on the top of the casting, a plan view can be projected on to the horizontal plane, and by looking at the front, the front view or elevation can be projected on to the vertical plane. If this pair of planes is then opened out flat, as shown in (*b*), the elevation will appear at the top and the plan directly underneath it.

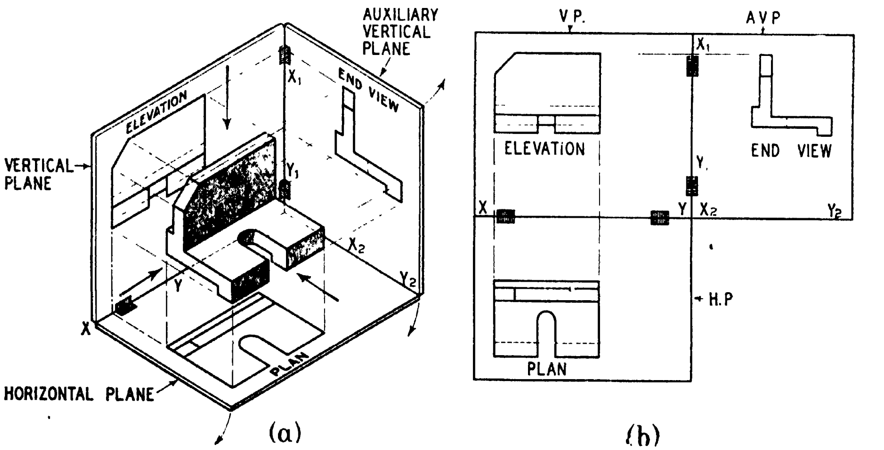


FIG. 2.—ILLUSTRATING FIRST ANGLE PROJECTION OF ELEVATION, PLAN, AND END VIEW

Showing the same principle applied to obtain plan, elevation, and end view. Note that the end view is the view seen when looking at the end farthest away from the end view. Compare with Fig. 6 (*b*), showing third angle projection.

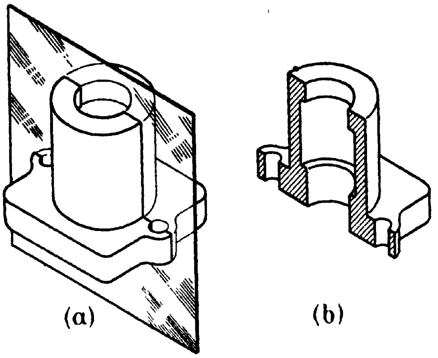


FIG. 3.—ILLUSTRATING THE PRINCIPLE OF SECTIONING

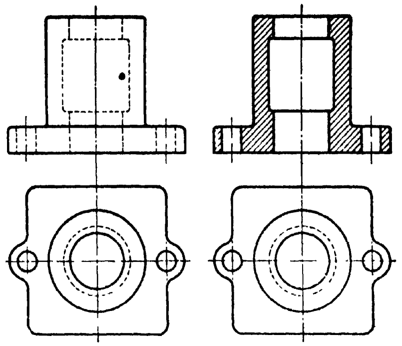


FIG. 4.—TWO ALTERNATIVE METHODS OF INDICATING THE SHAPES OF HIDDEN PARTS

In the case illustrated the new view obtained may be regarded as a second plan projected from the elevation. Note that all the widths in this plan must be the same as the corresponding widths shown in the original plan. Wherever such a view is shown on a drawing, the view should be suitably marked, e.g. "View looking in the direction AA," or "Section on AB."

Third Angle System

In the Third Angle System, generally employed in America, and to an increasing extent in this country, the component to be depicted is imagined to be behind the vertical plane of projection and beneath the horizontal plane. This is illustrated in Fig. 6 (*a*). The views are projected on to the horizontal and

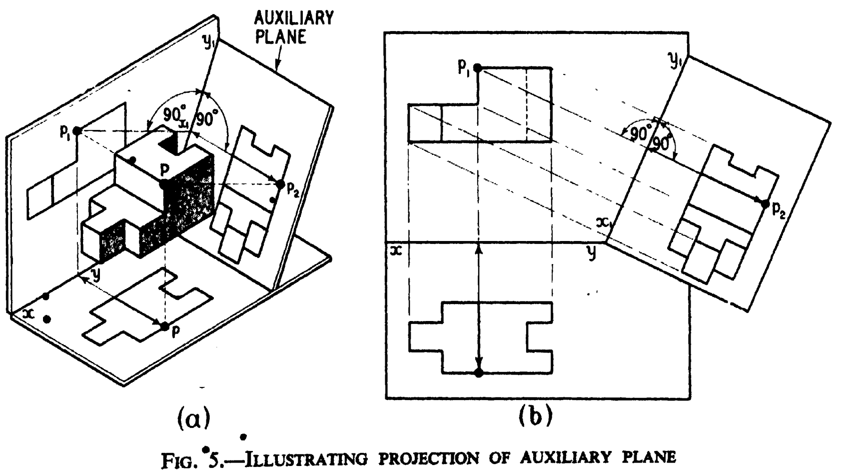
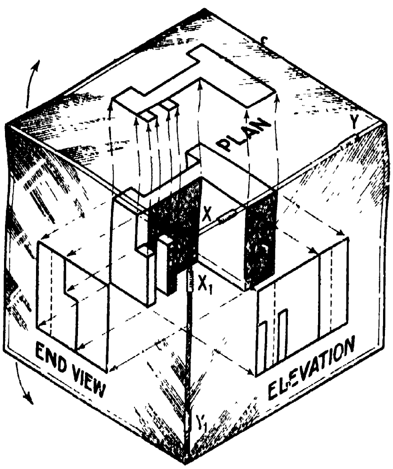
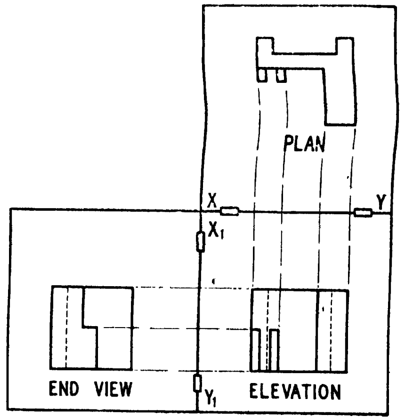


FIG. 5.—ILLUSTRATING PROJECTION OF AUXILIARY PLANE

THIRD ANGLE PROJECTION



(a)

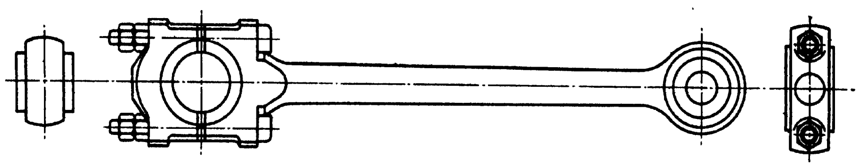


(b)

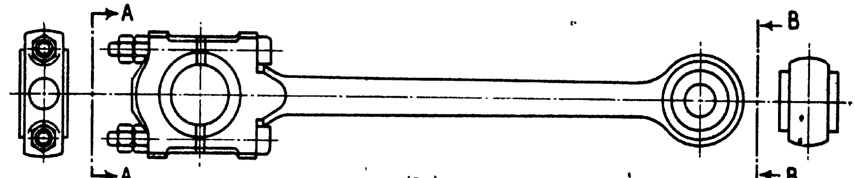
FIG. 6.—ILLUSTRATING THIRD ANGLE PROJECTION OF ELEVATION, PLAN, AND END VIEW

The component to be depicted is imagined to be behind the vertical plane of projection and beneath the horizontal plane, as shown in (*a*). The views are projected on to the horizontal and vertical planes, which then open out flat as shown in (*b*). Note that the plan in this case is above the elevation, and the end view is the view that would be seen looking at the end nearest to the end view.

COMPARISON BETWEEN FIRST AND THIRD ANGLE PROJECTION



(a)



(b)

FIG. 7.—SHOWING ADVANTAGE OF USING THIRD ANGLE PROJECTION

(*a*) First angle projection. (*b*) Third angle projection.

It will be seen that the end view of the big end of the connecting rod in the third angle system is adjacent to the elevation view of the big end.

vertical planes, which then open out flat as shown in Fig. 6 (*b*). Note that the plan in this case is above the elevation, and the end view is the view that would be seen looking at the end nearest to the end view.

By comparing Fig. 2 (*b*) with Fig. 6 (*b*), it will be seen that there is a decided difference in the two systems.

In reading a blue print it is most important to ascertain first whether the views are shown according to the First Angle or Third Angle System.

We have already seen that the advantage of the American or Third Angle System is that each view represents the side of the object nearest to it in the adjacent view. This advantage is very well illustrated in Fig. 7 (*a*) and (*b*). Fig. 7 (*a*) shows a long connecting rod with end views shown in First Angle Projection. Fig. 7 (*b*) shows the same rod with the end views shown in Third Angle Projection. This latter method is frequently adopted in British practice, but it is most important that arrows, such as *AA* and *BB*, shall be used to indicate the direction from which the view has been taken.

Location and Size Dimensions

A machine part may be regarded as a connected group of geometrical solids. When reading a drawing it is convenient to be able to distinguish between those dimensions which specify the size of the separate solids and those which locate the relative positions of these solids.

In Fig. 8 the location dimensions (*L*) are shown, and in Fig. 9 the size dimensions (*S*) are shown.

These two figures should be compared with the finished dimensioned drawing which is shown in Fig. 10.

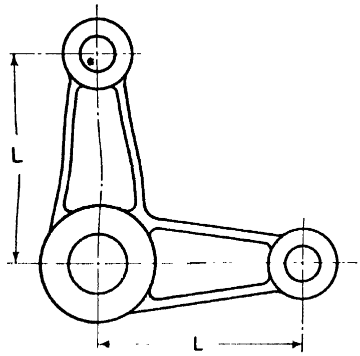


FIG. 8.—SHOWING LOCATION DIMENSIONS

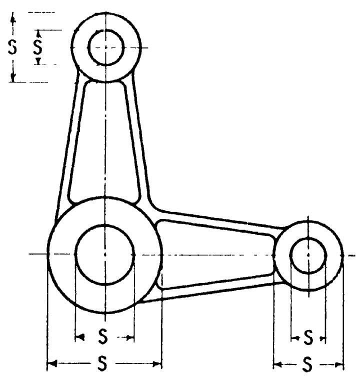


FIG. 9.—SHOWING SIZE DIMENSIONS

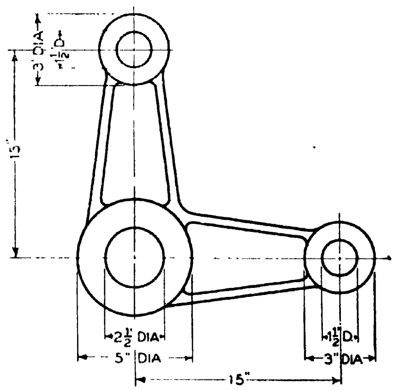


FIG. 10.—THE FINISHED DIMENSIONED DRAWING

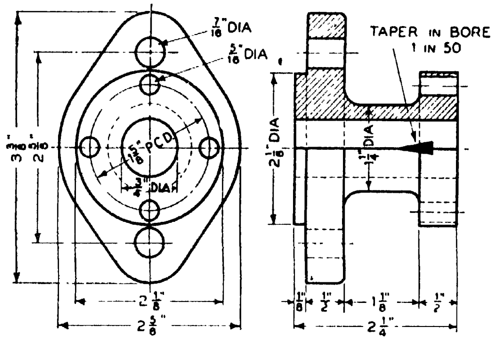


FIG. 11.—ANOTHER EXAMPLE OF A CORRECTLY DIMENSIONED DRAWING

General Notes on Dimensioning

The correct dimensioning of a drawing calls for considerable thought, and we now deal with the ready interpretation of working drawings. As shown in Figs. 10 and 11, both dimension and extension lines should be thin and continuous, the latter being broken at the outlines of the views. Dimension figures should be placed in reasonable positions and arranged so that they are not crossed by any other lines.

The conventions generally adopted in Britain and recommended by the B.S.I. are given below:

1. Dimension figures to stand normal to the dimension lines when reading from base to right-hand side of the drawing, and to be inserted in a break in the dimension line.
2. All vulgar fractions to be written with the line dividing the figures parallel to the dimension line.
3. Decimal points should be bold, and, in dimensions other than tolerances, should be preceded by a figure or cipher.
4. All dimensions should be direct, i.e. they should not involve calculation. Overall dimensions should be given.
5. The diameter of a complete circle should be given in preference to the radius. Diameters of pitch circles should be followed by the letters P.C.D. If a circular part appears in one view only, but not as a circle, the word "dia." should follow the dimension (for a square part, "sq.").
6. A taper should be defined as the alteration in diameter or thickness per unit length, the latter being measured along the centre line. When the direction of a taper is not evident from the drawing it should be shown by a wedge on the centre line.

Fig. 11 shows a fully dimensioned drawing embodying the above conventions.

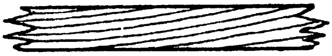


FIG. 12.—SECTION OF WOOD WITH GRAIN

FIG. 13.—SECTION OF WOOD ACROSS GRAIN

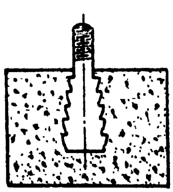


FIG. 14.—SECTION OF CONCRETE

Colour of Lines

Coloured lines should be avoided as far as possible, but when essential, centre lines should be brown and dimension lines blue, with black arrowheads and figures.

It should be noted that

o facilitate reproduction by photo ›rinting brown should be used instead ›f red and a mixture of Prussian blue .nd Chinese white instead of blue.

ɪow Materials are indicated on Drawings

Different materials should be in- licated by notes on drawings and racings, and any special means used o indicate different materials, such as ›y hatching or colours, should be ;hown by a note or in a key diagram ›n the drawing or tracing.

The only exception to this is in the :ase of wood or concrete, which should ɔe indicated in the manner shown in Figs. 12, 13, and 14, where a convention is required.

Various Degrees of Finish

Notes or key diagrams on drawings should be used to indicate the following degrees of finish:

1. Parts to be rough machined, finish machined, ground polished, or otherwise finished in any particular way.
2. Parts to be painted, rust-proofed, or otherwise coated.
3. Parts to be hardened or other- wise heat-treated.

Conventional Representation of Nuts and Bolts

Fig. 15 shows a sectional view of a coupling. Note that the two ends of the shafting are shown in elevation. The two halves of the coupling are shown in section, whilst the nuts, bolts and washers are again shown in full eleva- tion. Note carefully the conventional method used for showing hexagon bolt head and hexagon nut.

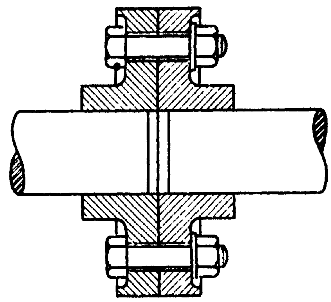


FIG. 15.—CONVENTIONAL METHOD OF INDICATING HEXAGON BOLT HEAD AND HEXAGON NUT

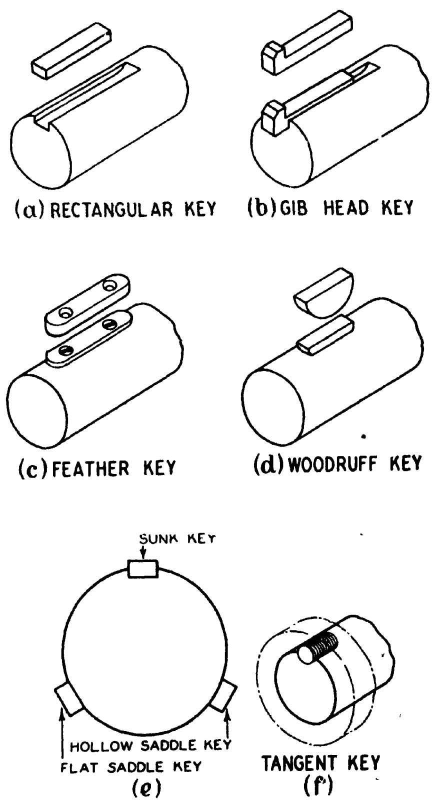


FIG. 16.—STANDARD TYPES OF KEYS

The diameter of the bolt head and nut are each equal to twice the diameter of the bolt shank. Hexagon nuts and bolt heads are usually shown with three sides of the hexagon visible. Square-headed bolts are indicated by diagonals drawn across the face of the nut or bolt head.

Keys and Keyways

Standard types of keys are used for securing wheels on shafts and spindles. Very often on a drawing the type and size of key are specified, and it is left to the fitter to fit a key in accordance with standard practice.

Fig. 16 shows the standard types of keys which are used, namely, the *rectangular key, the gib-headed key, the feather key, the woodruff key, the* hollow and flat saddle keys, and the tangent or grub-screw key.

The most commonly used are the rectangular and gib-headed keys, the latter being most particularly favoured where ease of dismantling is an important feature.

The feather key is used for a wheel which has to be capable of sliding on the shaft.

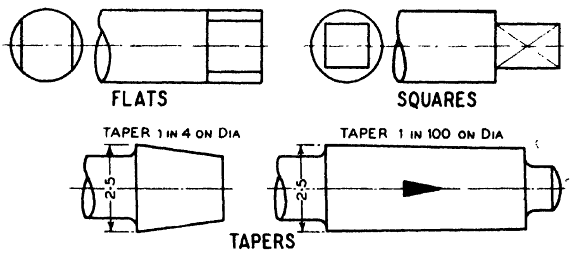


FIG. 17.—CONVENTIONAL METHODS OF INDICATING FLATS, SQUARES, AND TAPERS

A woodruff key is particularly suitable for conditions which preclude the cutting of a long keyway in the shaft. The recess for the key can be most easily cut in the shaft by the use of a milling cutter of a diameter corresponding to the size key to be used.

Saddle keys are only suitable for light service. Their use avoids the necessity of cutting a keyway in the shaft.

The round key or grub screw is suitable for light service where ease of fitting and dismantling are of prime importance.

Conventional Representation of Flats, Squares, and Tapers

Fig. 17 shows the conventional method used on a drawing for indicating flats, squares, and tapers. Note that where a taper is very slight the direction of taper should be indicated by a wedge on the centre line of the tapered component.

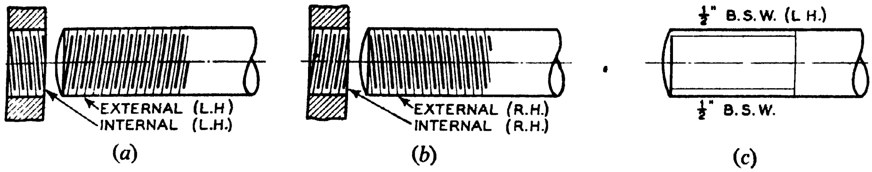


FIG. 18.—CONVENTIONAL REPRESENTATION OF SCREW THREADS

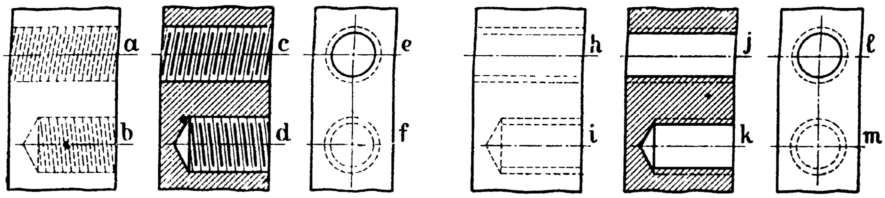


FIG. 19.—CONVENTIONAL REPRESENTATION OF INTERNAL SCREW THREADS

Screw Threads

For drawing screw threads, it is usually sufficient to show the threads by neans of a straight thin and full line. Where a left-hand thread is shown on the lrawing, it should be marked L.H. For indicating right-hand threads, the ıbbreviation R.H. is not necessary.

It will be seen from Fig. 18 (*b*) that the right-hand thread, which is, of course, he thread most usually met with, is shown by alternate thick and thin lines loping from right to left in an upwards direction. It will be seen also from this, ınd also from Fig. 18 (*a*), that the internal thread when shown in section slopes n the opposite direction to the thread as shown on a bolt.

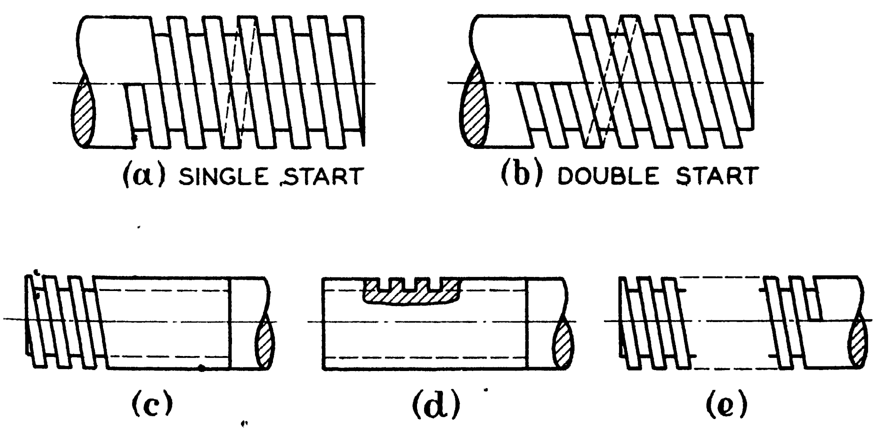


FIG. 20.—CONVENTIONAL REPRESENTATION OF SQUARE THREADS

As has already been mentioned, it is most important that any left-hand thread shall be clearly marked on a drawing "L.H. thread." Nevertheless, the mechanic is advised to memorise the appearance of right- and left-hand threads as an additional safeguard.

Where the style of thread is not specified, it can be assumed that a Standard Whitworth thread is to be cut.

An alternative B.S.I. method of showing a thread is shown in Fig. 18 (*c*).

The method employed for depicting internal threads is shown in Fig. 19. Fig. 19 (*a*)–(*d*) show what may be called regular thread symbols. Fig. 19 (*h*)–(*k*) show simplified symbols. End views of tapped holes are generally shown as in Fig. 19 (*e*), (*f*), (*l*), and (*m*). Ends of tapped holes are generally shown as in Fig. 19 (*b*), (*d*), (*i*), and (*k*).

Square Threads

Square threads may be represented as in Fig. 20 (*a*) and (*b*), or as shown in Fig. 20 (*c*) and (*d*). Fig. 20 (*e*) shows a typical American method.

In dealing with multiple threads, it should be borne in mind that the pitch and the lead are not the same, whereas in the case of single start threads the lead is the same as the pitch. In the case of a double start thread, the lead is equal to twice the pitch. In the case of a triple start thread, the lead is equal to three times the pitch, and so on.

E. M.

WORKSHOP METALLURGY

THE intensive development of specialised properties in metals began with the era of automobiles and aircraft: the engineer no longer accepts undesirable changes in properties resulting from detrimental constituents or cold working. Instead, he organises his alloying, his cold work, and heat-treatment to produce the qualities he most desires.

Metallurgists have provided constitution diagrams which show suitable heat-treatments for a wide range of alloys; micro- and macro-examination of crystal structure show grain size and arrangement, as a guide to heat-treatment or an indication of the cause of a breakdown; alloys of great strength have been developed by adding small quantities of the rarer metals, and stainless steel is one of the spectacular advances in this field; surface-hardening by induction produces a hardened case of the exact thickness and location desired in a matter of seconds, so that this process has become one of the high-speed production tools.

Advances in metallurgy enable the engineer to obtain desirable qualities in his finished product—strength, ductility, hardness, conductivity, resistance to shock, corrosion, creep, fatigue.

Of course, he cannot have a maximum of each of these in any one product; but modern methods of dealing with the crystals, as by heat-treatment, centrifugal casting, or induction-hardening, enable him to select the best possible combination of properties for his needs.

Constitutional Diagrams

When any liquid solidifies, the process may be styled "freezing." It would be possible to produce a curve, styled a freezing curve, showing the variation of temperature with time, as the temperature falls and the liquid approaches nearer to the freezing-point. A sample of such a curve is provided in Fig. 1; it will be seen that at one point the temperature remains constant, due to latent heat, while the liquid solidifies, and then continues with approximately the same slope or inclination after this process is complete. A similar curve could be drawn for the solidification with falling temperature of any metal.

The solidification of two metals, producing what is called a binary alloy, follows the same process. But usually the solidifying temperature of one of the metals will be lower than that of the other; and a cooling curve takes the form of that shown in Fig. 2. Here we see the solidification of one metal, then the continuation of the curve at the same slope as before until the solidification

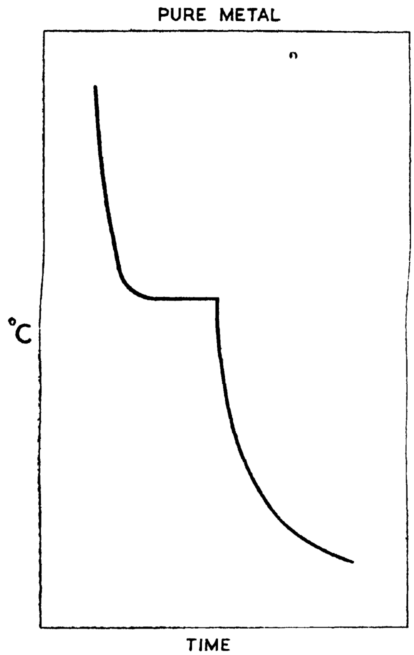


FIG. 1.—COOLING CURVE FOR PURE METAL

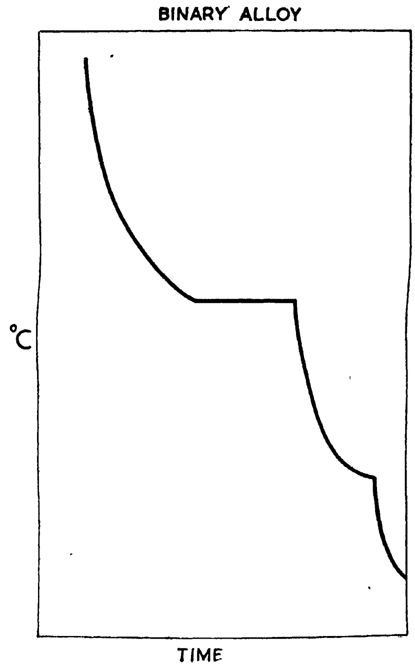


FIG. 2.—COOLING CURVE FOR A BINARY ALLOY

temperature of the second metal is reached, and then the fall of temperature at the original rate.

The upper solidification point of this curve will vary with the composition of the alloy: Fig. 3 shows how the position of this point varies as the composition of the alloy changes, stated as a percentage of the two metals.

At the extreme left hand of this chart the metal is not an alloy: it consists of the pure metal, and the freezing-point at this side of the diagram is that of 100 per cent. of the metal with the higher freezing-point. At the extreme right-hand side of the diagram, the material consists of 100 per cent. pure metal with the lower freezing-point, and the curve at that point corresponds, therefore, to the freezing-point of the pure metal with the lower solidification temperature. If we were to join up the upper and lower solidification points of each of these curves by lines *ACE*, *BCD*, we should obtain what has been styled as an equilibrium diagram. Above *ACE* the metal is liquid; below *BCD* the metal is a solid. Whether liquid or solid, it consists of a solution in varying proportions of one metal in the other.

Referring again to Fig. 3, it will be seen that point *C* is common to both sets of curves.

This is the point at which the alloy of lowest melting-point is produced;

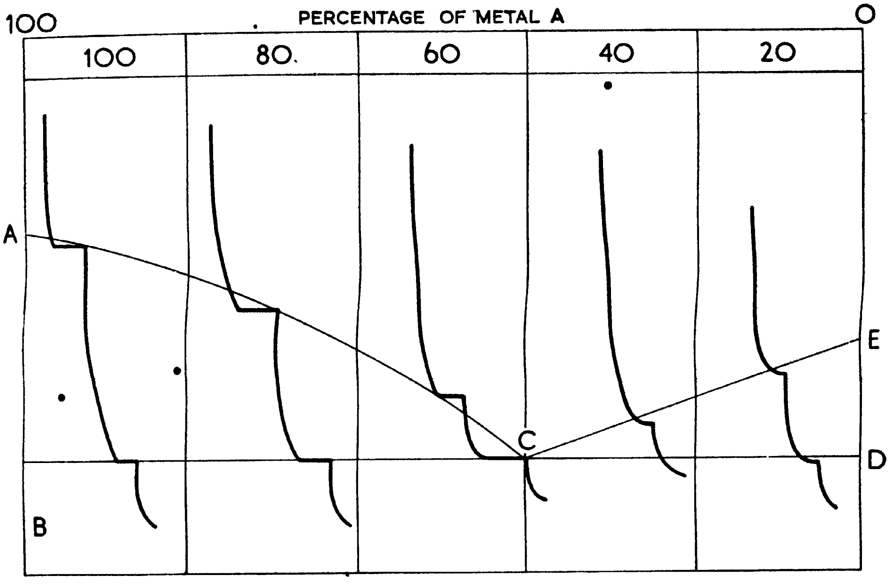


FIG. 3.—SET OF COOLING CURVES

These curves illustrate the variation of the upper solidification point with the composition of the alloy.

an alloy in these proportions is termed the eutectic alloy, and that point on both curves is styled the eutectic point.

It will be noticed that the curve joining the upper series of freezing-points falls from *A* to *C*, and rises from *C* to *E*. The horizontal portion from *B* to *D* is constant at the eutectic temperature; and below the line *BCD* the whole of the frozen metal is solid, above the two curves *ACE* the whole of the metal is liquid. The part at the top is therefore styled a liquid (liquidus), and the part below is styled the solidus. The upper shaded portion in Fig. 4 shows the temperatures above which the metal is liquid; the temperatures below which the metal is solid are indicated in the lower shaded portion; in the two white triangles left unshaded the metal is neither solid nor liquid, but is a sludge or slush until the temperature reaches the lower point at which complete solidification takes place.

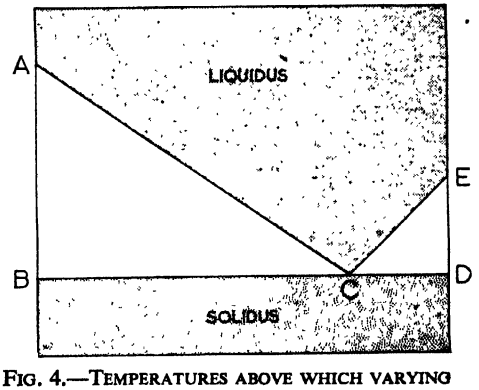


FIG. 4.—TEMPERATURES ABOVE WHICH VARYING PROPORTIONS OF TWO METALS WILL TURN LIQUID

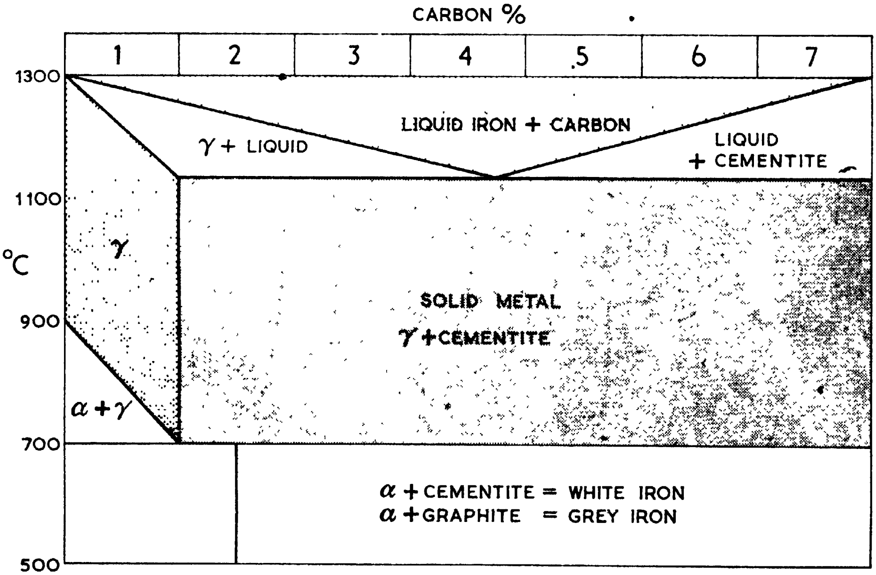


FIG. 5.—FOR ANY PERCENTAGE OF CARBON SHOWN ACROSS THE TOP THE DIAGRAM INDICATES ON A LINE DRAWN VERTICALLY DOWNWARDS THE CHANGES OF CONSTITUTION

From the fact that the line *BD* is horizontal, we may deduce that at all points below that line a certain quantity of eutectic alloy (the alloy of least fusibility) is present. This is in fact confirmed by micro-pictures.

Crystal Structure of Metals

Just as with water, crystals are produced in the pure metal. Sometimes they are large enough to be seen by the naked eye, but generally a magnification of at least twenty times is desirable with a microscope. When so magnified it can be seen that these crystals do not correspond to the regular and sometimes beautiful forms of those found elsewhere, but are a rough series of areas approximately round or rectangular, provided that the hot metal has not been worked. The size of these crystals is dependent upon certain features, such as rate of cooling or the method of heat-treatment; but in the unworked metal, the shape remains approximately that of a roughly drawn square or circle.

When the metal is worked, the crystals are distorted; for example, rolling into a flat sheet pushes them over side-ways and the square-shaped crystal becomes a long thin rectangle.

In general, the larger the crystals the more ductile the metal; certain forms of heat-treatment result in an increase in the size of the crystals known as grain growth; and except where it is intended that the crystal shall grow to this

size, this may be an undesirable feature of the treatment of the metal. As stated, it results in a metal more ductile, but giving a lower tensile strength.

Where crystals, or the grainflow lines, are visible to the naked eye, examination need not be conducted by means of a microscope. The surface of the specimen to be examined must be specially prepared by polishing and etching, as with those intended for micro-examination. When this is done, as for example with an ingot, the crystals may be generally arranged in the following manner. On the outside of the material there is a series of small crystals at the point where the molten metal is cooled by contact with the mould; growing inwards from these are a series of needle crystals as the material cools from the outside inwards; and finally, the core of the ingot consists of crystals approximately rectangular without their axes lying in any definite plane.

Work Hardening

Cold working of any metal, such as by rolling, drawing, pressing, beating, spinning or stamping, increases its hardness and tensile strength, but reduces its ductility, and if cold working (strain-hardening) is carried too far, the metal may crack. The degree of cold working which a material will withstand depends on its composition and initial hardness.

If, after cold working, a metal is heated above a certain temperature (the recrystallisation temperature), softening occurs and the process is known as annealing. Work-hardened alloys which have been annealed cannot be restored to their original strength except by further cold working.

It is unsatisfactory to exceed appreciably the required temperature, as this tends to increase the grain size of the metal. Prolonged soaking at or above the recrystallisation temperature is also undesirable. Excessive crystal—or grain—growth reduces the mechanical properties of the metal, and may give an undesirable "orange-peel" effect on the surface when the material is subsequently worked.

It is desirable to obtain the soft fine-grained material required in as short a time as possible, but abnormally short annealing times make accurate control somewhat difficult. Rapid heating to the required temperature is important, as slow heating to the annealing temperature favours grain growth.

Carbon Steels

The great variety of carbon steels is shown by the equilibrium diagram, Fig. 6.

Taking any percentage of carbon such as 0·5 and beginning at the top of the diagram, we shall find ourselves with a type of iron styled "gamma" iron, after the Greek letter γ; this type of iron exists only at temperatures above 1,900° C.

Below that temperature, another type of iron styled "beta" (β) iron occurs; it exists only between 900° C. and 700° C., as the temperature falls. Below 700° C. there exists a third type of iron styled "alpha" (α) iron. In the equilibrium diagram constructed to show solid solubility, the points of rest are not freezing-points but change of structure.

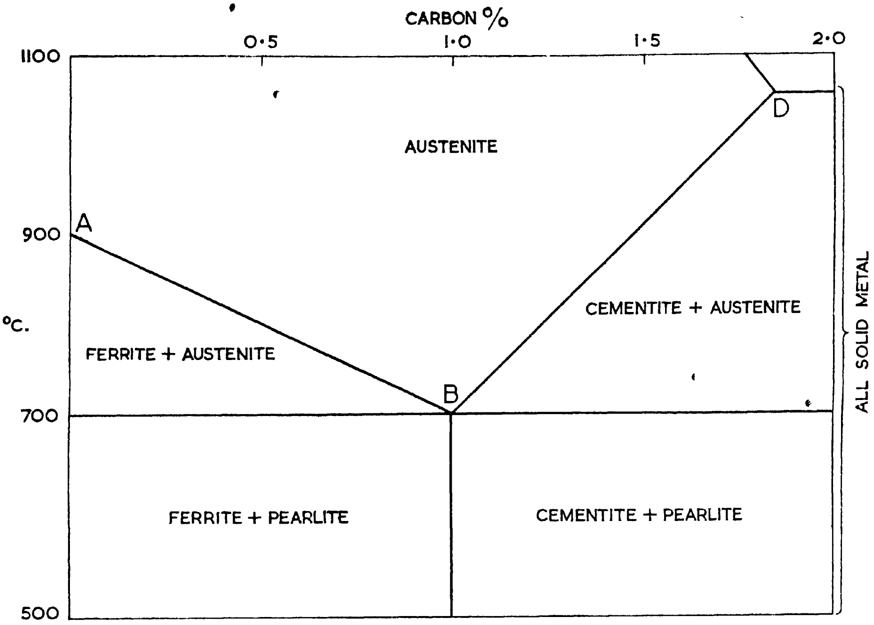


FIG. 6.—AN ENLARGEMENT OF THE BOTTOM LEFT-HAND CORNER OF FIG. 5, SHOWING THE ALLOTROPIC CHANGES IN A SOLID SOLUTION OF CARBON IN IRON

The three types of iron or steel so produced are said to be allotropes, and the changes are allotropic. Three allotropes of the familiar carbon are charcoal, coal, or the diamond. In the top triangle of this diagram, all the steel (a combination of iron and carbon) will be of a type based upon the iron which has been styled gamma iron; and in this form the steel has been styled "austenite."

As the temperature falls, we reach the line *AB*; below that point at which the austenite ceases to exist in the pure state, there will be another constituent, "ferrite"; this again is only a solid solution, but it is based upon alpha iron.

As with the cooling of liquid solutions, there is a point *B* in this diagram which corresponds to the eutectic point, that point at which an alloy of the lowest fusibility exists; it will be recalled that a certain proportion of any solidifying or solid solution consists of the eutectic alloy, a mixture of the two metals or constituents which behaves in its cooling exactly similarly to a pure metal; that is, for example, it has only a single step in its freezing curve.

The Eutectoid

When the solution is a solid one, and the allotropic changes are brought about by falling temperature, the point corresponding to the eutectic is called the "eutectoid," and here again, in the solid solution, the pure eutectoid behaves exactly as if it were a single constituent undiluted by any other.

On either side of this eutectoid point as regards variation in the percentages of carbon in the steel, the cooling material results in a different crystal structure. In both structures there will be a quantity of the eutectoid, in which crystals of other materials are embedded. The other materials to the left of the line *BX* consist of crystals of iron carbide called ferrite; to the right of the line *BX* the crystals in the eutectoid are styled "cementite."

Despite all these variations, in any one type of steel the changes in structure are only allotropic; that is, these different forms of steel differ in physical qualities in much the same way as the carbon in the diamond is hard, while that in charcoal is soft.

In dealing with this diagram, we have assumed that the temperature is falling so slowly as to permit the structural changes in the steel to take place fully, a process which may take a long time. If, on the other hand, the cooling were to be very rapid, other allotropic forms of steel are produced; with the most rapid type we get "martensite"; with less rapid cooling but still too fast for normal structural formation "troostite" results; and with only moderate cooling, "sorbite" or "sorbitic pearlite," a pearlite in which the crystals form an extremely fine structure.

Allotropic Forms of Carbon Steel

At this stage it will be as well to define the range of seven allotropic forms of carbon steels:

(1) Austenite is a solid solution of cementite in gamma iron.

(2) Low-carbon steels consist of a mixture of ferrite and the eutectoid pearlite.

(3) The next important allotrope is the pure pearlite, formed at the eutectoid point.

(4) With increased proportions of carbon, the structure still consists of a high proportion of pearlite, but there is an excess of cementite, iron carbide, a hard and brittle constituent.

There are forms of steel produced by slow cooling the different types. The three other constituents are produced by rapid cooling, as stated previously.

Alloy Steels

Even in some of the simplest steels in common use to-day, small quantities of alloying metals are used. These metals include manganese, nickel, chromium, molybdenum, and vanadium. In recent years, steels of very high tensile strength have been produced by the addition of very small quantities of these metals; and perhaps the best example is D.T.D. 331, giving a tensile strength of practically 90 tons per square inch.

The addition of small quantities of the alloying metals produces a wide variety of changes in the finished steel; and here it will only be possible to give the engineer a rough idea of the purpose of the addition of the various elements.

MANGANESE.—Manganese is almost the most important element other than carbon; its addition in small quantities reduces the ferrous oxides and counter-

acts the harmful influence of iron sulphide, both of which impurities reduce the strength of the steel. It has other beneficial effects, especially if the carbon content is slightly reduced; thus, while the ultimate tensile and yield point figures may remain the same with increased manganese content, elasticity and Izod figures are greatly improved.

NICKEL.—The addition of nickel to steels also results in an increase of the strength, yield point, and hardness; it is most important to notice that these improved properties are achieved without materially affecting the ductility. Normally in non-alloy steels an increase in the ultimate tensile strength is offset by a decrease in the ductility, especially as reflected in the Izod test. The use of nickel also has advantages from the point of view of heat-treatment. It slows down the rate of hardening and so increases the depth, and produces a structure consisting of finer grains with improved resistance to corrosion. A comparatively high proportion of nickel is used in stainless steel D.T.D.166 B, the most important steel for high-tensile, non-corrodible plate fittings.

CHROMIUM.—Chromium alloys are used where considerable wear resistance is required; like nickel, the addition of this metal imparts hardness, strength, and corrosion resistance. It should be added that chromium improves the magnetic qualities of steel.

NICKEL-CHROMIUM.—Combinations of nickel and chromium possess greater advantages than either of these alloys used separately; nickel counteracts a tendency to grain growth resulting from the use of chromium, while chromium permits higher tempering temperatures to be employed by raising the critical points.

MOLYBDENUM.—Molybdenum is also effective in reducing the grain size, and increasing elasticity, impact value, wear resistance, and fatigue strength. Extremely small quantities are employed, and this small percentage has as much effect as larger quantities of the other alloying elements.

VANADIUM.—Vanadium is the most expensive of the alloying metals. It improves the grain structure and fatigue strength, as well as being advantageous for the ultimate tensile strength and resistance to impact. These steels combine high strength and good ductility.

Heat-treatment of Steels

It will be seen that variation of the rate of cooling off a particular type of steel will result in formation of its physical properties, especially those affecting its hardness, ultimate strength, and ductility.

Hardening.

Rapid cooling or quenching may result in retaining at low temperatures a structure which is normal at high temperatures. For example, the change from austenite to pearlite is normally slow; but if we drop an austenitic steel at a temperature above the line *AB* into cold water, the transition is arrested; from this rapid quenching a hard and brittle material results, with the added disadvantage that shrinkage strains are produced. If we now reheat this strained

metal almost up to the line AB or BD (depending on its carbon content), the normal changes are allowed to proceed a little farther and the shrinkage strains are reduced. This may produce moderate hardness and somewhat reduced strength, a much more useful state of affairs.

This operation is styled hardening; a steel is heated to a temperature of say 50° above the critical line, and maintained at that temperature long enough to result in solution of the cementite in the gamma iron; this process is styled soaking. If the temperature is too high or the soaking period too long, grain growth takes place and the structure will be of low tensile strength.

Maximum hardness is obtained where martensite has been produced; and here the speed of quenching will result in a harder steel, the degree of hardness depending on the carbon content as well as on the quenching speed.

Annealing

An entirely different result is obtained by slow cooling; that is, the steel is annealed to just above the critical line, and cooled very slowly in the furnace. It then retains a fine-grained structure, is ductile and comparatively soft, but without a high ultimate tensile strength. There is, of course, no objection to another type of heat-treatment being applied after all mechanical working has been completed.

Normalising

Normalising is a form of annealing in which the steel is quenched in air, a much more rapid method than cooling in the furnace itself. As may be expected, the steel is stronger and harder, but less ductile than in the annealed form. But normalising will relieve any stresses resulting from the original cooling, will refine the grain, and make steel more uniform. On account of the increased ultimate strength, aircraft steels are usually worked in the normalised condition rather than in the annealed form. It is considered necessary to normalise welded parts.

Tempering

Hardening is a heat-treatment intended to produce a high-strength steel; here again the metal is heated above the critical line, soaked at that temperature to secure uniform heating throughout, and then quenched in salt water or oil. The metal has a fine grain, maximum ultimate tensile strength and hardness, but minimum ductility. Its internal structure results in some martensite and some troostite, the former responsible for the extreme hardness and brittleness of the steel.

The brittleness at least has a disadvantage, quite apart from the presence of internal strains. We apply to this extremely hard steel another form of heat-treatment styled tempering, where the hardened steel is heated to a temperature below the critical line, soaked until uniformly heated, and once again quenched, this time in brine, water, oil, or air. This process results in increased ductility and decreased brittleness, despite a certain reduction in ultimate tensile strength.

Surface Hardening

The product of any of the above forms of heat-treatment will consist of the same allotropic form of the metal all the way through, with the possible exception that extremely rapid cooling may result in patches which differ slightly from the constitution of the rest of the mass. There is, however, another process of heat-treatment which is of the greatest use to the engineer; that is, surface-hardening, in which the surface of the metal is of a different structure from the remainder. This is of use to us where the metal has to be applied to any form of shaft or bearing where long life is required despite continuous wear. The hardened surface is frequently described as the case; and one of the processes is styled case-hardening.

Carburising, Cyaniding, and Nitriding

The hardening of the case may be brought about by heat-treatment of the metal in contact with three materials, and the different methods are styled accordingly, carburising, cyaniding, and nitriding.

In all three, the heated metal is either brought into contact or maintained in contact with the hardening material; if it is to be carburising, the parts are packed in a metal box and all surfaces covered with at least an inch of the charcoal or carburising material; the furnace is brought up to a temperature of about 1,650° F., and held for a varying time depending upon the depth of case required.

Carburising can be carried out in a liquid salt bath to which the appropriate quantity of carbon has been added; and a still more recent process case-hardens steels in an electric furnace, with a carbon atmosphere.

Similarly, cyaniding is merely the heating of steel in contact with a cyanide salt, followed by quenching. It is not a process which is very much used with aircraft steels.

Nitriding is applied to special alloy steels used chiefly in connection with the engine rather than in the airframe. A hard case is obtained, produced by heating the metal in contact with ammonia gas or other nitrogen compound. The heating may continue for as much as seventy-two hours, and the case produced is very brittle. No quenching is required by this process, which may supersede carburising.

As the quenching of carburised steel may result in internal strains, it is necessary to temper the parts immediately after quenching them. A furnace or oil bath may be maintained at the tempering temperature, and the parts soaked until heated uniformly; they are then removed and cooled slowly in still air.

Sintering

Sintering is a process in powder metallurgy in which metallic powders cake or coalesce under the influence of heat, usually accompanied by pressure. The temperatures required can be rapidly reached throughout the mass of the

powder metals by means of radio-frequency heating. (The subject of "Powder Metallurgy" is dealt with in greater detail in Volume II.)

The process produces mixtures of metals with special mechanical and magnetic quantities.

Sintered carbides are used for high-speed cutting tools and valve seats. They are produced by sintering together, at about 1,500° C., the hard carbides of tungsten or tantalum with ductile cobalt. The metal powders, with different melting-points, are heated to the temperature approximating the lowest melting-point of any metal included. The cobalt acts as the binder holding together the unmelted particles of the hard carbides.

Mixtures of powdered copper, tin, and graphite can be moulded under pressures of 40,000 lb. per square inch and sintered. This process is used in the manufacture of bearings, the graphite making them self-lubricating.

Ageing, or Age Hardening

Certain alloys, particularly the non-ferrous ones, are subject to a precipitation of hardening constituents at room temperature. Precipitation following solution treatment means the same for alloys as it does for a solution of salt or sugar in water; at lower temperatures a smaller amount of copper is held in solution by aluminium, and may be precipitated as the temperature falls.

The precipitation must, of course, be preceded by solution treatment, in which the temperature of solid alloy is raised to an amount at which the aluminium solvent will dissolve the required amount of copper or other solute. An alloy rapidly quenched from this temperature may hold in solution practically all the dissolved solid copper, but in age-hardening alloys which are permitted or helped to age, metallic compounds that have a hardening effect may be precipitated.

Artificial Ageing and the Prevention of Ageing

This precipitation or hardening may take place spontaneously and slowly, or may be induced by slight rise of temperature; and this latter is styled artificial ageing. Thus in duralumin ageing is induced by a temperature no higher than 160° C., and can be greatly hastened merely by immersing the parts in boiling water. The opposite process would be the prevention of ageing: thus dural rivets which had hardened would not spread into a head without cracking; and must therefore be kept at a temperature much lower than that of the factory, i.e. in a refrigerator.

These double-treatment alloys can, however, withstand a certain amount of cold work after quenching, as ageing may take some days naturally; re-solution treatment is not required unless the working operations are severe. Precipitation-treatment, or artificial ageing, can then be carried out at any time to secure hardness and maximum strength.

Artificial ageing, where it is permitted, may have to be carried out at a low temperature where a large batch of work has to be packed into a furnace. An alloy may be fully aged in three hours at 300° C., but it may take more than

two hours to bring the temperature of the whole load up to this figure. It would be advisable to apply a lower temperature, say 160° C., and extend the time as required, which might be twenty hours in all.

At one time there were objections to the artificial hardening of alloys which would age naturally over a week or so; but for British Standards 4L25 and 478 (Y-alloy), ageing by boiling in water was permitted for one hour, instead of waiting five days at room temperature.

Radiographic Inspection

This valuable process reveals invisible faults in welds of all types, such as those produced by too rapid cooling, or gas bubbles resulting from an excess of acetylene, causing the weld to be porous. Blowholes, fissures, and inclusions can be detected in castings. Iron and steel may be examined even when 5 in. thick, and depth of penetration into aluminium and magnesium is more than 10 in. and 18 in. respectively.

Crystal Examination

In X-ray crystal analysis, the ray is diffracted from the surface of metal and recorded on a photographic film, in a spectrum which varies according to the material and its metallurgical condition. The ray penetrates below the surface of the metal, and is refracted from crystal surfaces invisible to the eye of the microscope, thus revealing changes in three dimensions.

Crystal examination will detect and record strain, such as that resulting from machining, and release of strain following heat-treatment, the effects of rolling, drawing, and extrusion; the effect of heat or mechanical treatment on grain size; and the presence of surface plating or oxide scaling, amongst other surfaces, and their physical and chemical condition.

British Standards Institution Specifications

Engineering and aircraft metals are sold, bought, wrought, cast, machined, heat-treated, and tested with the aid, as a reference standard of quality and method, of British Standards Institution Specifications. A full list appears in the *British Standards Yearbook*, issued by the Institution at 24/28, Victoria Street, London, S.W.1. The index shows about fifty publications on the various steels, including the aircraft steels; and a single one of these booklets, No. 970, "provides a schedule of some ninety wrought carbon and alloy steels for automobile and general engineering purposes. For each steel the chemical composition, condition of material on delivery, heat-treatment, and the mechanical properties obtained from test pieces are specified." No. 1392 gives details of the transformation ranges in the heat-treatment of steel.

There are fifty publications on aluminium and its alloys in various forms, including the aircraft or D.T.D. specifications. Methods of testing, applicable to all metals, are laid down in B.S.S. 18 for tensile tests, 131 for Izod and Charpy tests of impact on notched bars, 240 for Brinnell, and 890 for Rockwell hardness tests.

G. W. W.

PATTERN-MAKING IN WOOD AND METAL

PRODUCTION of good pattern equipment requires a craftsman who, in addition to possessing skill and technical knowledge, can quickly form a mental picture of his objective from the drawings, sketches, specimen castings, or any of the similar primary information passed to him for the first step in *practical* engineering effort. This is because the actual pattern may, for technical reasons to be explained later on, bear little or no visible appearance to the shape of the final casting.

Foundry Knowledge

Budding pattern-makers are strongly advised to visit as many different foundries as possible, where they would, by seeing patterns and coreboxes in use, gain knowledge essential to the making of an efficiently workable pattern, since it is to the foundry that the product of the pattern-maker is conveyed, and in that establishment used as a tool of first importance.

WOOD PATTERN-MAKING

Drawings and Machining Allowances

Where patterns are required for very large quantities of castings, the modern engineering or foundry practice is to prepare and send to the pattern shop a complete set of drawings which embody all the permissible tapers, tolerances, and machining allowances, in addition to indicating moulding method and various other technical refinements.

For the majority of wood patterns the actual machine or component drawing is handed to the pattern-maker, and as this drawing represents the *finished* part, a mark (usually the letter "F") is made against surfaces to be machined by the engineer, and it is then necessary for the pattern-maker to allow an extra amount of material on his pattern to provide for accurately machining the casting where so indicated.

The usual machining allowances are $\frac{1}{8}$ in. for ferrous and $\frac{1}{16}$ in. for non-ferrous metals. Variations above and below are dependent upon the size of the casting.

Contraction Allowances

Special rules which have contraction allowances already made are obtainable from any tool merchant. For the benefit of readers who desire to know the

FIG. 1.—PARING GOUGE WITH "CRANKED" HANDLE IN USE

Note the hand clearance which permits working in any direction, regardless of the length of job or the tool.

actual allowances, they are as follows: cast iron, $\frac{1}{120}$; brass, gun-metal, and phosphor-bronze, $\frac{1}{70}$; copper, $\frac{1}{48}$; aluminium, $\frac{1}{77}$; steel, $\frac{1}{48}$; malleable iron, $\frac{1}{60}$ to the inch or foot.

The Pattern-maker's Tools and their Selection

In addition to the usual wood-worker's kit, it is well for the pattern-maker to pay attention to detail in the selection of the following tools:

FIG. 2.—A USEFUL TOOL FOR THE PATTERN-MAKER

Large diameter being checked with calliper points in trammels. These points or rods are held by setscrews which permit changing to divider points for marking out.

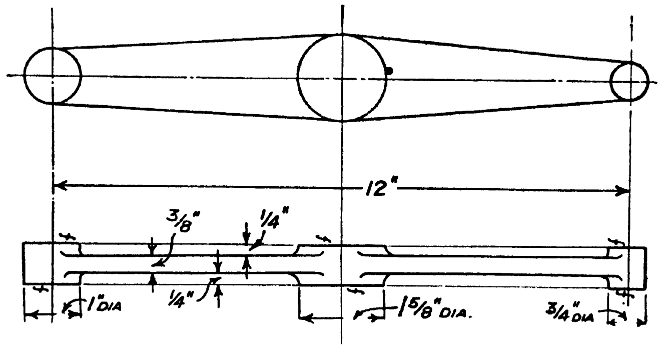


FIG. 3.—A SIMPLE LEVER
Example taken to illustrate how to make simple patterns.

Gouges for paring should have a set or "crank" (see Fig. 1); the usefulness will afterwards be shown.

A small round-sole spokeshave.

Trammels with detachable points which can be replaced with calliper points (see Fig. 2).

A router plane (sometimes called "old-woman's tooth").

For the remaining bulk, the skill with which a man handles his own particular possessions is sufficient for him to be the best judge of his own requirements.

Dealing with Simple Patterns

In the majority of cases, it is not necessary to "mark out" or "lay out" a simple pattern. This need only occur in the case of the more involved patterns, which we will deal with in due course.

Let us take the simple lever (Fig. 3). Looking at the drawing we see that it comprises a plate $\frac{3}{8}$ in. thick with three bosses on either side finished $\frac{1}{4}$ in. thick, diameters 1 in., $1\frac{5}{8}$ in., and $\frac{3}{4}$ in. We "get out" these various parts as analysed, adding machining allowance to the thickness of the bosses, fix the bosses to the plate when all have been made to size, and there we have the pattern ready for finishing.

Turning Small Bosses

A hint here for turning small bosses such as these will not be out of place.

Plane up a piece of wood, the finished thickness of the required bosses, large enough to cut out each boss $\frac{1}{8}$ in. larger than the finished diameter of the extreme edge of the fillet radius. Now prepare a chuck (Fig. 4), driving two nails diametrically opposite, and within a circle a little smaller than the finished diameter of the boss. Cut off the heads of the nails, leaving a good $\frac{1}{4}$ in. still projecting. File these to a sharp point. The discs to be turned may now be pressed or tapped gently on to the chuck within a guiding circle, and are held quite firmly enough to have the periphery turned as required. This system is useful in that it enables the bosses to be turned quickly and cleanly, also a true centre may be marked while the work is still in the lathe.

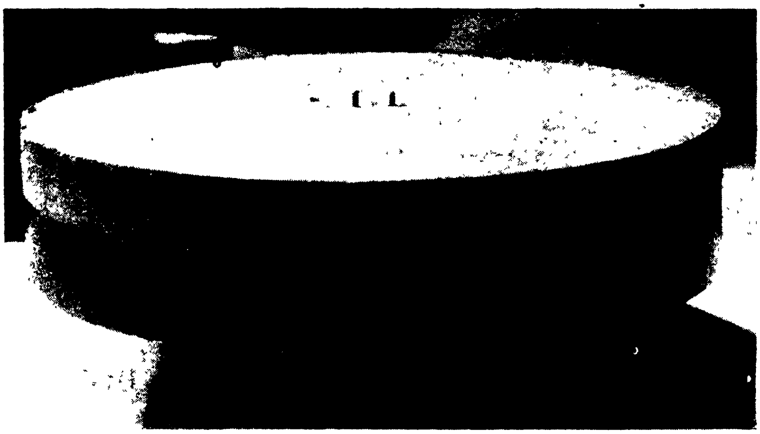


FIG. 4.—CHUCK OR FACEPLATE PREPARED FOR THE TURNING OF SMALL BOSSES

Planing Flat and True

There are few hard-and-fast rules in pattern-making, but one which, although not always essential, is always useful, is to true-up one flat face and one square edge. A steel rule (not folding) is quite a good straightedge, and the test is made by holding the rule on edge (Fig. 5) against the wood, particularly testing from corner to corner to eliminate twist.

Selection of Timber

Quebec pine, Canadian sugar pine, and Idaho white pine are mostly favoured for general purposes, Honduras mahogany, teak, and Cuban mahogany being used for more permanent patterns. Straight-grained and essentially dry wood should only be used at all times. Warping and twisting is a bugbear to pattern-making, but wet timbers aggravate shrinkage and irregularity after finishing, which might mean scrapping the job.

Taper for Patterns and its Application

The moulder who uses the pattern will appraise such points as exaggerated taper on shallow webs and the like. It is quite obvious that the best castings are obtained from patterns that will leave the mould easily; therefore, as part of the technical additions that must be made, a very important one is the thickening and thinning of metal and coreprints.

A guide for an average amount of taper arranged on everyday jobs such as brackets, end frames, and bedplates, is $\frac{1}{16}$ in. in 3 in. Variations above and below this amount are dependent upon the design of the casting, such things as webs spaced very closely together and like occurrences requiring more taper than in ordinary circumstances.

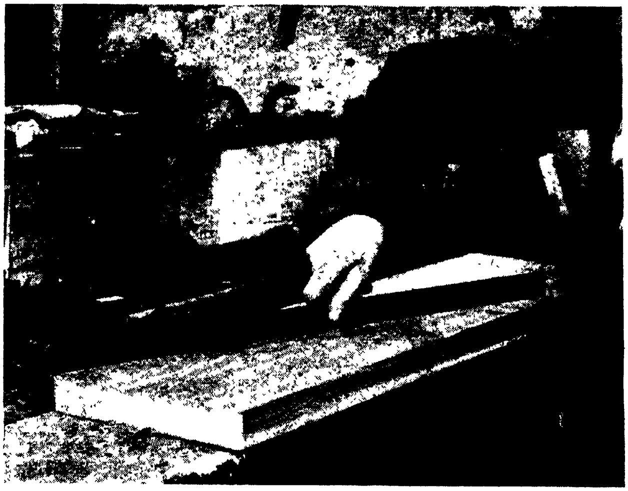


FIG. 5.—TESTING THE FLATNESS OF A PIECE OF WOOD WITH STRAIGHTEDGE

Arrangement of Grain

Consideration given to the arrangement of the way of running grain, before actually preparing the wood for any pattern, is vital for these reasons: strength and durability, the elimination of wasting the material, and facilitating moulding. The first two points will be dealt with later in our methods of making particular kinds of patterns. In all cases, however, it is desirable to avoid making up a surface that has a side draw in the mould, with the grain running a number of different ways.

BUILDING UP BY SEGMENTS

Segments are mostly used for building up wheel rims, although in the course of engineering practice we often find other jobs where segments may be applied to advantage.

Mark Out Master Segment as a Template

Let us take a simple ring as a beginning—mark out a segment of one-sixth the periphery, allowing sufficient for machining the pattern on the radii and a little in the length for fitting. This master segment we use as a template, by which we mark out the remaining number of segments required. These, of course, will be six for every layer of segments to be built up.

Building Up a Simple Job

The procedure is now simple and obvious. While not always practicable, it is advisable wherever possible to take a wooden faceplate and chuck which runs true in the lathe, mark on a circle for the inside and outside diameters of the ring, and commence building up by fastening one segment in position with two nails (heads clipped off) after trimming ends, and proceed by laying seg-

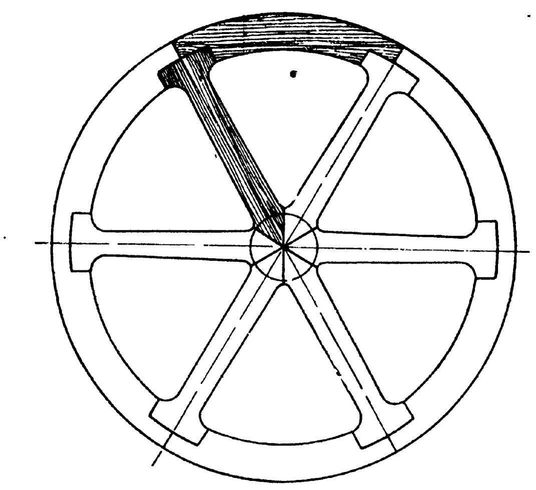


FIG. 6.—THE WAY TO RUN GRAIN, SHOWN BY SHADING, ON WHEEL BUILT UP WITH SPOKES

ments in their correct position between the two circles and trimming the ends to fit. When putting on second layer of segments, place the first segment so that joint of two below is covered, as in bricklaying.

Another Way

Rings may also be built up separately from the chuck by marking out the circles on a flat board, and immediately the building up is finished it will be found that the ring is quite strong enough to handle and screw, or fasten in any suitable manner on to a chuck ready for turning.

Methods of Making Wheels with Spokes

We will take for an example a spur wheel with six arms. After marking out full size on the laying-out board, by drawing a centre line between each arm, we find that, analysed, the wheel comprises a simple ring (for the periphery) and six spokes which shape like a spearhead where they meet at the centre boss. We prepare material exactly to meet this description (Fig. 6).

Building up the Job

Lay the six spokes (which, by the way, should be long enough to enter deeply into the rim) in their position as marked on the board. Next a segment is fitted between each spoke, after which the rim is completed in similar fashion to the building up of a plain ring. Assuming that the spokes are thinner than the rim of the wheel, it will be necessary when turning to rechuck the job.

Having turned all the faces available by first chucking, remove job, and fix three or four small pieces on to the chuck inside a circle which is a little larger than the inside diameter of the rim of the wheel. True these up in the lathe until the turned inside diameter of the wheel will fit over tightly. An extra fastening by screw or nail is advisable wherever possible, although not always essential.

Large Wheels and Circular Patterns

In Fig. 7 the foundation of a sheave wheel, 10 ft. in diameter, is seen. Note that there are eight spokes, and in this instance eight segments. The number of segments may be increased to effect economy of timber in addition to the purpose of avoiding "short grain." Large work such as this must be progressed from

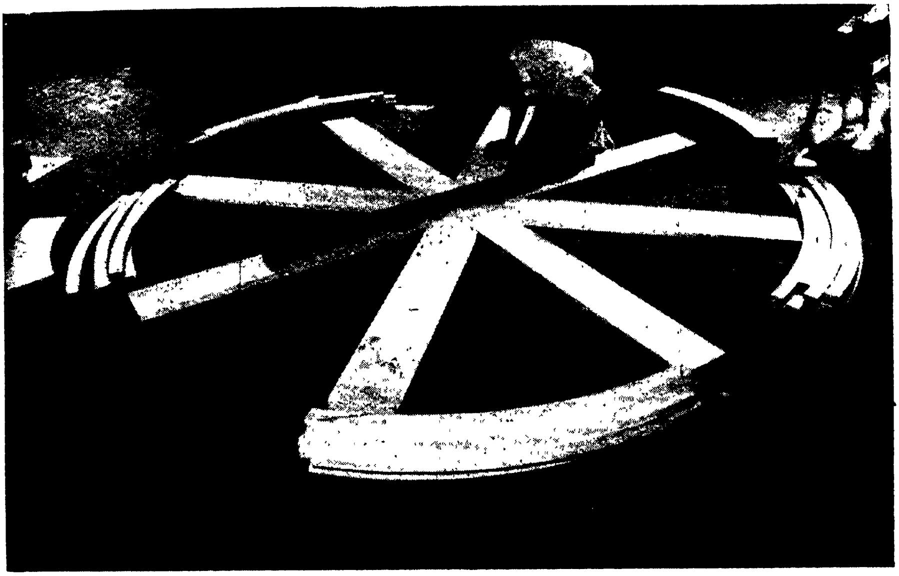


FIG. 7.—TESTING LEVELS OF FOUNDATION ARMS AND SEGMENTS FOR 10-FT. DIAMETER WHEEL PATTERN BUILT UP ON FLOOR

a "setting out," and in Fig. 8 the pattern-maker is seen checking his building up from his own full-size setting out, and a close scrutiny of the right-hand side of the illustration will show where the layer thicknesses and widths were marked. This is to ensure no shortage of material when finally cutting the pattern to shape by milling or turning.

As this particular example of circular job has a very broad outer rim, a glance at Fig. 9 will show how the timber used is kept to a minimum consistent with rigidity and stability of dimensional accuracy. Although not seen, further strengthening blocks were added in the hollow rim to give additional support at the butt joint of each outer layer.

Having completed the building up of the pattern, the next step is to turn or machine the job to its true shape. For such large work as illustrated, the lathe is not always the best medium to perform the machining, and in Fig. 10 we see the method of mounting the 10-ft. diameter wheel on to the rotating tables of a *pattern-milling* machine. The work is then slowly revolved on its horizontal plane as now fixed to the machine, and in Fig. 11 the pattern-maker is seen controlling the adjustable head of the miller, which is now in process of cutting the pattern to shape by means of variable-shaped cutters revolving at high speed on the adjustable head. The pattern now being somewhat cumbersome, an additional helper is employed to turn the pattern on the revolving tables of the machine, and so give the machine operator fullest freedom to watch the shaping as it progresses. It is noteworthy that this method is actually

FIG. 8.—AS THE LAYERS OF SEGMENTS ARE ADDED TO THE PATTERN, EACH STEP AND CHANGE IN RADIUS IS CHECKED FROM THE "SETTING OUT"

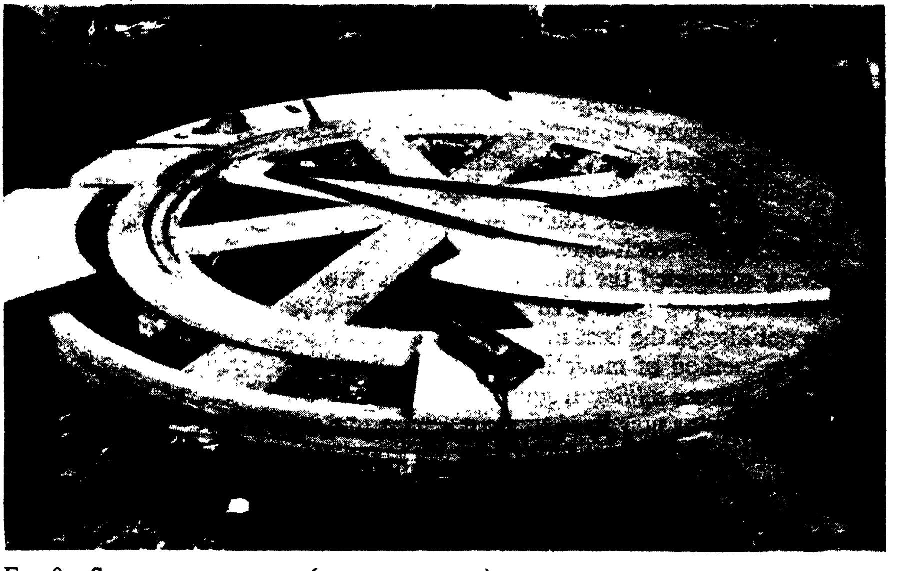


FIG. 9.—SHOWING THE DOUBLE (INNER AND OUTER) COURSES OF SEGMENTS TO SAVE MATERIAL IN BUILDING UP LARGE CIRCULAR PATTERN

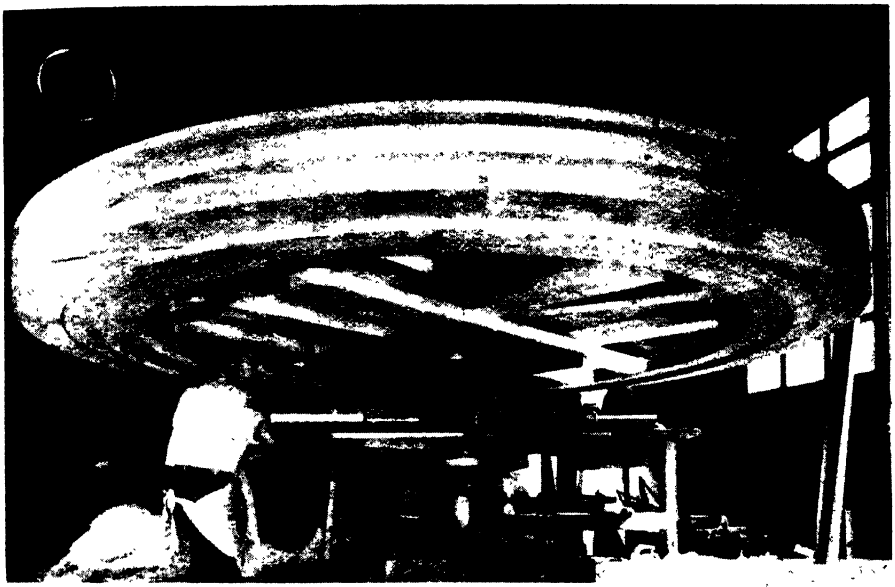


FIG. 10.—FASTENING THE 10-FT. DIAMETER WHEEL PATTERN TO THE ROTARY TABLE OF A PATTERN MILLING MACHINE. VIEWED FROM BELOW THE WORKING POSITION

FIG. 11.—VIEW ABOVE THE OPERATOR'S HEAD DURING THE TURNING AND SHAPING OF THE 10-FT. DIAMETER WHEEL ON THE PATTERN MILLER

FIG. 8.—AS THE LAYERS OF SEGMENTS ARE ADDED TO THE PATTERN, EACH STEP AND CHANGE IN RADIUS IS CHECKED FROM THE "SETTING OUT"

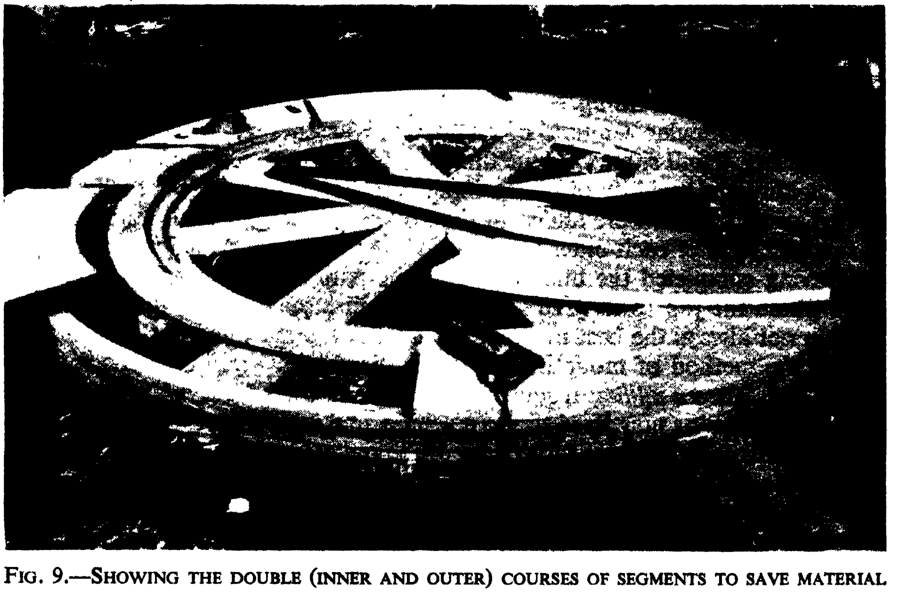


FIG. 9.—SHOWING THE DOUBLE (INNER AND OUTER) COURSES OF SEGMENTS TO SAVE MATERIAL IN BUILDING UP LARGE CIRCULAR PATTERN

corresponding to the number of lags, which are usually determined by the diameter of the job: the larger the job, the more flats. When marking out the ends, for economy in using material, an extra flat may be found necessary in order to obtain two lags out of the width of a plank.

FIG. 13.—COREBOX FOR THE V-GROOVE OF THE SHEAVE WHEEL STANDING ON END AND WITH TOP PIECE OPEN TO SHOW INTERIOR

Building up Lags

On a flat board mark out a centre line. Fasten the two end pieces to the board the correct distance apart. Take care that each end is square up from the board, and that the centre lines match accurately with the one on the board. If these points are carefully watched at the beginning, the job is quickly completed and, above all, perfectly true. Proceeding, plane two edges of one lag to a bevel, which is obtained by following out a radial line. The width of the lag will, of course, be planed accurately to the length of the flat to which it will be fastened. Having fixed the first lag, care should be taken to see that the end pieces are still in their true position; then continue by fitting one edge of each other lag and marking the accurate width when holding it in position. Fix each lag immediately it has been fitted and planed to width. Any job built up this way may usually be worked upon without waiting for the glue to set.

COREPRINTS AND COREBOXES

Purpose of Coreboxes

The primary use of coreboxes is to obtain *spaces* in castings which would not come out of the mould if *cut* out of the pattern. For an example, take a tube with an outside diameter of 3 in., length 12 in., hole at each end $1\frac{1}{2}$ in. diameter for 3 in. along and the remaining 6 in. enlarged to $2\frac{1}{4}$ in. The pattern for this job would look like a simple roller with a small *peg* the diameter of the hole at the ends. These pegs are called *coreprints* (or shortly, *prints*) (Fig. 15).

The corebox is cut and made to suit the inside shape of the finished casting *plus* the coreprint.

FIG. 8.—AS THE LAYERS OF SEGMENTS ARE ADDED TO THE PATTERN, EACH STEP AND CHANGE IN RADIUS IS CHECKED FROM THE "SETTING OUT"

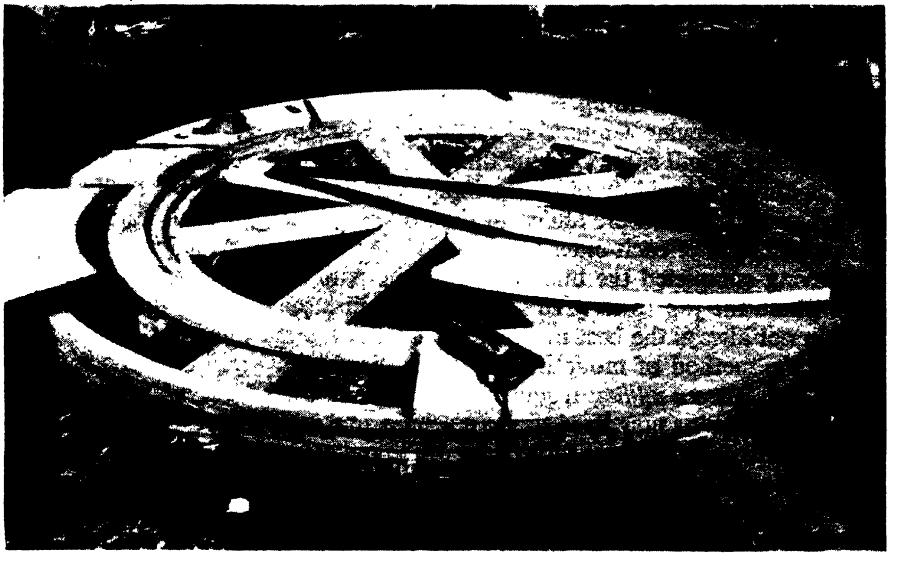


FIG. 9.—SHOWING THE DOUBLE (INNER AND OUTER) COURSES OF SEGMENTS TO SAVE MATERIAL IN BUILDING UP LARGE CIRCULAR PATTERN

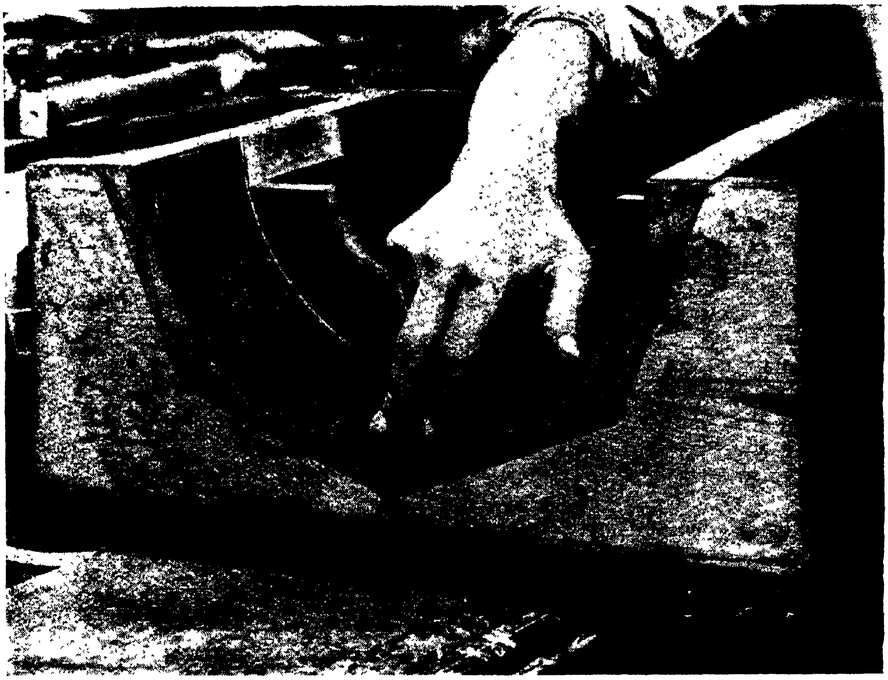


FIG. 16.—SHOWING CONSTRUCTION OF LAGGED-UP COREBOX

desired casting. The emphasis of this point is made, because there are many jobs which can be cast by clever moulding, such as false cores, etc., but in every-day engineering practice the pattern-maker seeks to design his arrangement of coreprints, etc., to speed up and facilitate production.

A Simply Constructed Pattern with Corebox and Coreprint

We take as our example an electrical terminal box (Fig. 15). Similarly designed patterns to this are always in great demand. The pattern to the illustration drawing could be made to mould without any core whatsoever, but when it is desired to take, say, twelve castings off, the duty of the pattern-maker is to make a *strong job* consistent with *easy moulding*. This would be as follows:

Make a Full-size Section

Having marked out a full-size section and determined the size of coreprint, the blueprint or drawing can be put aside, and all working dimensions taken from the layout.

Building up Boxed Pattern

A box is now built up large enough to incorporate the "print," but minus any projection. When building up a "boxed" pattern, it is well to keep, say,

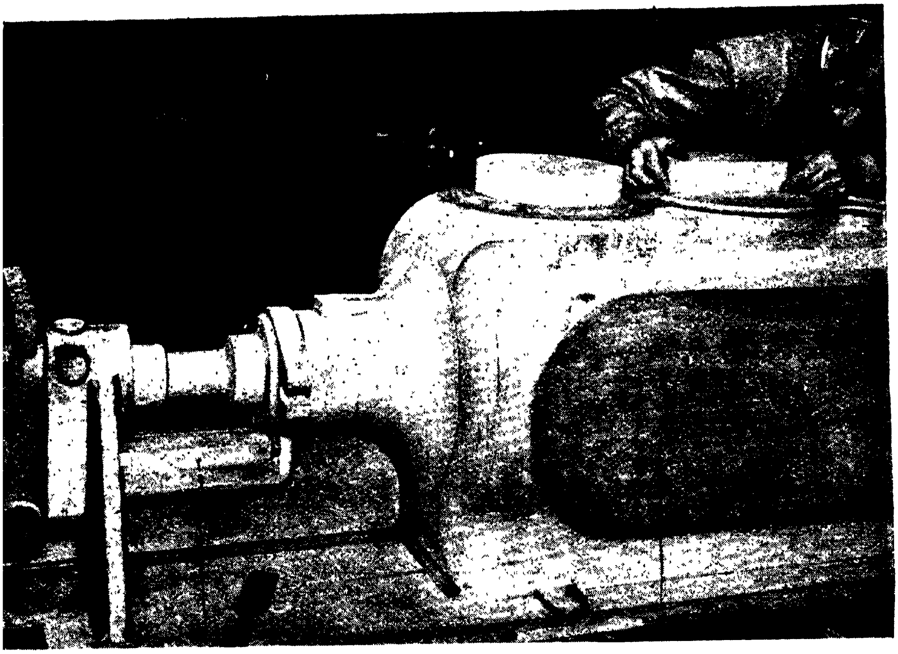


FIG. 17.—AFFIXING COREPRINTS TO CRANKCASE PATTERN

$\frac{1}{16}$ in. oversize, so that the "box" can be squared and planed dead true after assembling. This will be found essential in all similar patterns, as it is seldom that a box when put together is perfectly true, owing to the number of pieces used, any of which, if the smallest amount out in size, etc., will throw the whole job out of square.

Add Bosses and Lugs

Now that the box pattern has been made, any bosses, lugs, or similar additions must be added before rounding any corners or edges. When adding parts to any pattern, as far as possible, it is best to work from *one* particular centre line or edge for all centres. When making a small channel section such as is used for holding rubber airtight packing, it is advisable to work same out of solid where practicable, or if made up of strips, not to *glue* leather fillet in corners, but to use thick shellac or put in a wax fillet. These precautions give good moulding effect and eliminate sand adherance in the groove.

Making the Corebox

The corebox, for a rectangular "box" pattern of average "terminal" size, is usually made in the "framed and housed" style (Fig. 21).

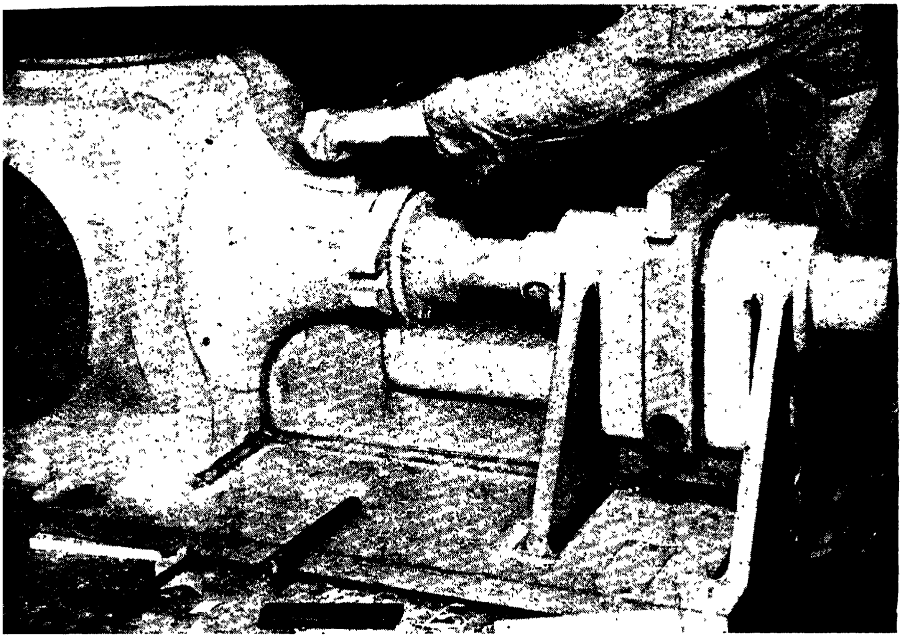


FIG. 18.—PLANING OFF THE FACE OF A BOSS PRELIMINARY TO MARKING CORRECT SHAPE
Showing constructional details of a crankcase pattern when nearing completion. Note that the bosses are first fitted and affixed in a very rough shape, although the surface worked on is in its final form.

Preparing the Raw Material

Take the depth of coreprint plus the internal depth of the casting (which total will be the *width* of the sides and ends) and add the length of coreprint and width together plus 6 in. (which total will allow of cutting off one side and one end for the corebox). The object of this method is to ensure that all sides and ends of corebox are equal in width, and is a quick way of planing them flat and true. Two pieces are thus required for each rectangular corebox, and when prepared can be placed edge to edge and the "housing" and lengths all marked off on the two pieces simultaneously. The usual amount for "housing" is approximately $\frac{3}{16}$ in., and care should be taken to allow this extra amount on each end of the end pieces of the corebox.

Screwing Pieces Together

When these two sides and two ends have been cut to size we will have four pieces ready for screwing together. Any bosses or internal projections may now be affixed to the sides or ends, and accuracy is facilitated by the fact that we are working on flat pieces of wood instead of the cramped space within a box. The "housing" ensures that the whole assembly remains the same every time

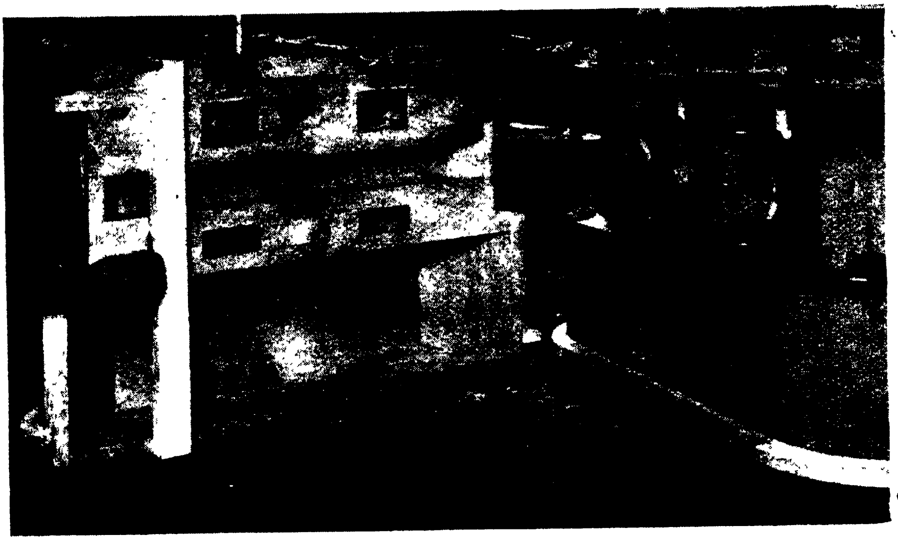


FIG. 19.—MARKING OFF THE POSITION OF STIFFENING BEAMS ON CYLINDER-BLOCK PATTERN

The particular point is to keep the job from breaking at joints. A further advantage is the lifting facilities gained for moulding the job.

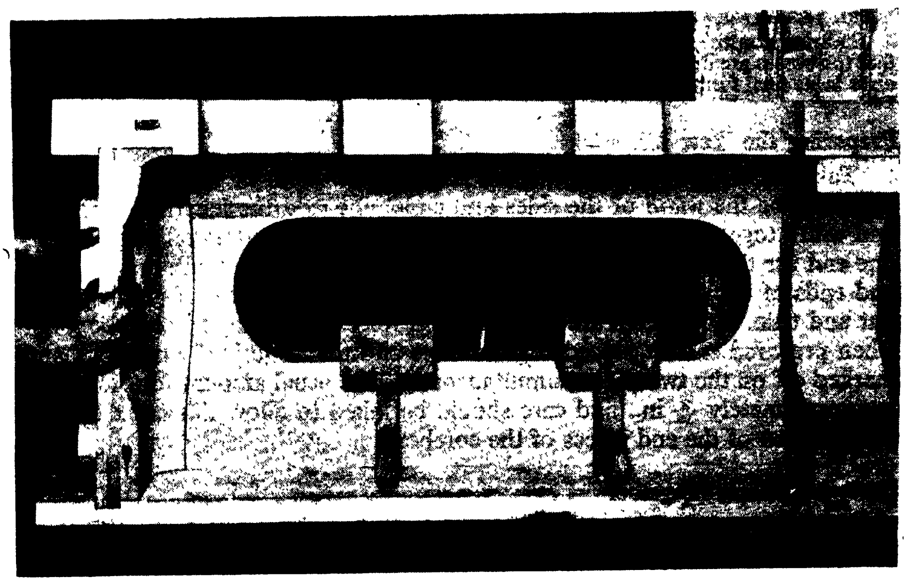


FIG. 20.—FACE VIEW OF HALF THE MAIN COREBOX FOR A CRANKCASE

Showing the advantage of a housed framework for removing ends to facilitate shaping and marking out.

the corebox is taken apart and put together, the latter being an occurrence which takes place each time a core is made, when there are a number of projections inside the corebox which prevent "shaking" the core out.

When dealing with a job which has a fillet or radius in the bottom corners and/or bosses, etc., on the bottom of the casting, a plate is dowelled or screwed (preferably dowelled) on to the bottom of the corebox to accommodate them. The fillet may be worked by recessing the bottom plate a depth equal to the radius of the fillet and carving the fillet out of solid. Alternatively, strips may be fastened on to the plate to give an equal result, and a leather fillet glued into the corners formed.

Bend Pipe Patterns and Coreboxes (or "Elbows")

Small "elbow" or bend patterns can be solid (say up to 1 in. diameter), but when making the pattern of any diameter which shows a deep half-parting line, it is best to split or make it in halves. There is also the added advantage of being able to mark the true radii on the actual line which finally finishes that shape.

Making Pattern for a Bend Pipe of 2 in. Outside Diameter

The raw material would be two pieces 1 in. thick and of area large enough to embrace the *metal* outside dimensions. Watching carefully that, as near as possible, the dowels are placed in the centre of the pattern (as it will be finished) but well apart, the two raw pieces are jointed and dowelled together. The thickness overall of the two pieces should now be a full 2 in. (or whatever is the outside diameter of the pipe being made).

Getting the Bend

Next, a square working edge is planed, holding both pieces together in a vice; if the bend is a complete 90° turn, a square edge at right angles to the first is planed. For our example we will assume that the latter is the job in hand. However, if the bend is more or less than a 90° turn, the procedure is exactly the same, but using a bevel set to the angle of the turn in place of the square the one way. Now the centre lines are marked on, the circles marked on the ends, and then the two pieces separated and the radii of the bend marked on the *joint*. The two halves may now be cut out, giving a bend which is *rectangular in section*.

Next, the corners of the rectangular section bend are cut away neatly and truly to make the bend into an octagonal section. A simple way of arriving at this result is to take a 45° bevel, mark same at tangent to the finished circle, then with odd-leg dividers produce the apex point on all edges and faces, except joint, of course. Having achieved a bend of octagonal section, it will be seen that by now removing the sharp corners all round (*with a spokeshave*), the pattern part of the bend is ready.

Fixing the Coreprints

The coreprints may now be affixed, and these will be the diameter of the *inside* of the casting and of sufficient length which makes the total cubic capacity

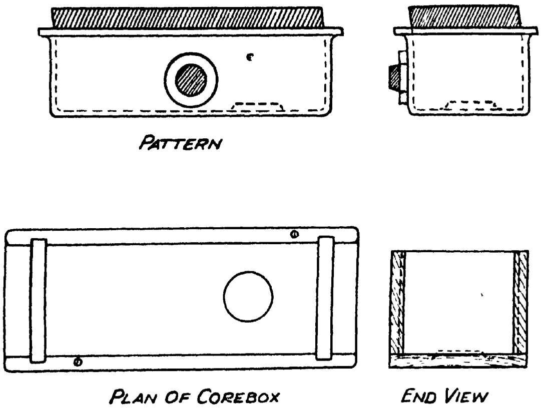


FIG. 21.—A BOX PATTERN WITH COREBOX OF FRAMED AND HOUSED TYPE

Shaded portions on pattern denote coreprint and the dotted lines the part which is cored away.

of *coreprint* equal to that of the actual inside contents of the casting or core. The particular method of fixing half-round coreprints (or whole diameter for that matter) depends on the design of the job in hand, and the various ways will be dealt with in taking long-barrelled bends, etc.

The Corebox for the Simple 2-in. Bend

Having finished the pattern, rough sizes can be taken off for the corebox, by allowing about 2 in. over the coreprints and for substance round the "corehole." Proceeding exactly as with the pattern, a joint of two pieces, this time with the dowels kept well away from the locality where the core-hole is to be cut, is squared off as before.

When allowing material for *thickness*, any small amount behind the half-circle will suffice, e.g. a hole or core of $1\frac{1}{2}$ in. diameter can easily be cut out of two pieces of material finishing $1\frac{1}{4}$ in. thick each; this would leave $\frac{1}{2}$ in. of stuff behind each half-circle. This of course is too thin for wear in the foundry, but would be reinforced by battens behind, which must always be fixed with the grain running in opposite direction to the main job. When cutting a bend it is not necessary to make a template of the half-circle in the corebox (although

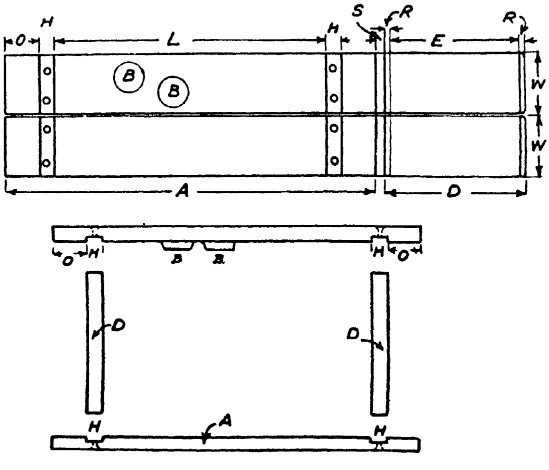


FIG. 22.—COREBOX FOR RECTANGULAR BOX PATTERN

A, total length of side. *B*, bosses which will not draw without detaching side. *D*, total length of end. *E*, showing length of end after assembly into rebate. *H*, rebate for housing. *L*, working face of side on core. *O*, overlap beyond housing. *R*, amount of end taken up by housing. *S*, sawcut allowance for parting end from side. *W*, width of sides and ends.

templates are always an asset where there is room for uncertainty).

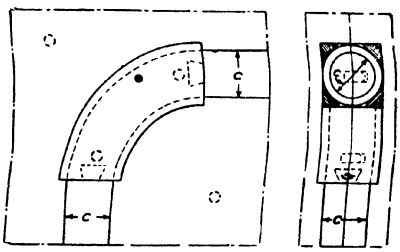


FIG. 23.—A BEND PIPE PATTERN (SPLIT) OF APPROXIMATELY 2 IN. OUTSIDE DIAMETER

Showing how body part is cut from the square section into octagonal (where shaded), then finally into the round section. *C* denotes the coreprints, which are added by the dovetail joint method. Chain-dotted lines show corebox material and disposition of dowels.

Pattern-maker's Test for Half-round Hole

The pattern-maker's universal test for any size half-round hole is to try in an ordinary set-square, the point or corner of which should just touch at any position. This method allows of a diminishing hole or tapered tube to be truly cut, without a number of templates.

A Word or Two Concerning Dowels and their Use

For service in wear, and time taken in inserting in any pattern or corebox, metal dowels are most economical and satisfactory to use. For those who do not wish to use metal dowels for any reason, wooden ones are quite suitable; but an important point in their use is to make sure that a nice taper is cut (to give an easy lead into the socket) and yet at the same time leave about $\frac{1}{8}$–$\frac{1}{4}$ in. of parallel projection for maintaining the correct alignment. Opposite centres may be obtained by placing a pin between the joint, smartly tapping the two parts together, and using the dent or impression caused by the head of the pin as the centre for boring the hole. Metal dowels mostly have provision made for this purpose.

A Point to Watch when about to Joint Two Parts

No matter whether a glued or dowelled joint is being made, see that the heart or pith of the tree is *away* from the joint. The reason for this practice is that wood warps or curls away from the pith, and when a pattern or corebox becomes old and is still in use, the joint will not rock. Furthermore, it becomes a simple matter to plane the joint true without affecting the correct dimensions.

Making a Large Corebox of Solid Timbers

Frequently it occurs that, although a large round pattern has been made up in the "lagged" style, the corebox is best made up of solid timbers, one advantage being that a solid-timbered corebox will stand a great deal more wear and knocking about. Another advantage is that any deep cavities or "cut-aways" that are required may be taken out of the corebox without fear of the weakening which would occur with a lagged-up box.

Building up Solid-timbered Corebox

The method of making is to mark out a semicircle of the core on a board. Bearing in mind that the thickest boards in general use are no more than 3 in

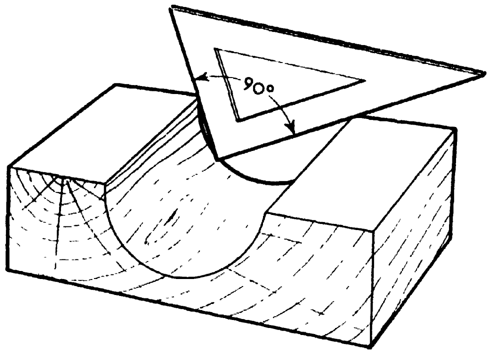


FIG. 24.—THE TEST FOR HALF-ROUND COREBOXES (TAPERED, ETC.) BASED ON USING A 90° SETSQUARE

The corner of the setsquare should touch at every point in the semicircle.

(which finish 2⅞ in. planed), start by marking in a baseboard 2⅞ in. thick which cuts part-way into the semicircle, leaving a good amount of material behind it, say about 1½ in. Then mark in two side pieces in similar fashion, but not taking in so much circle, in order to have more material behind the edge. Next the corners are filled in by measuring the quantity required, which, if exceeding the 2⅞ in. in both directions, will naturally need two pieces for each corner. Thus it will be seen that all the building-up process consists of is really a channel section of the correct length, perfectly square in every way and the corners filled in.

Marking Out and Cutting

It is inadvisable to put in any screws until the cutting is finished, so therefore care should be taken to see that all the glued joints are good and holding tightly. When the corebox is a long one, if machinery is available, the *joint* of the two halves may be taken straight off the planing machine, but if planed by hand, the eye will tell where to take out twist and unevenness better than a straight-edge on a job of this nature.

Having made a joint of the two half-coreboxes, and dowelled them with plate-type dowels, which can easily be removed, square one edge and true up the ends of box to this.

Then cramp or dog the two halves tightly together, plug a strip in each end so that a line producing the joint line may be drawn across, and gauge the centre of the hole off the square edge of the outside. The circle at each end may now be struck, and will truly be in line with its opposite.

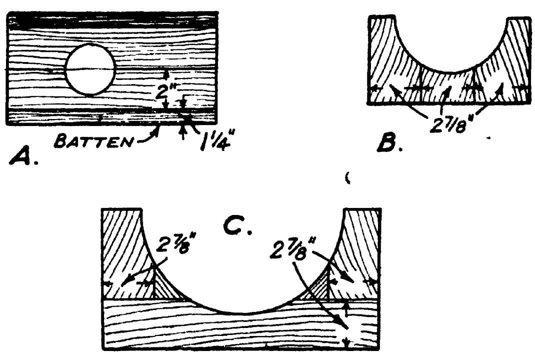


FIG. 25.—THREE DIFFERENT WAYS OF BUILDING UP COREBOXES

A, general-purpose corebox. *B*, medium large size, where 3-in. timbers can be applied as shown. *C*, large corebox, where solid timbers are required instead of lags.

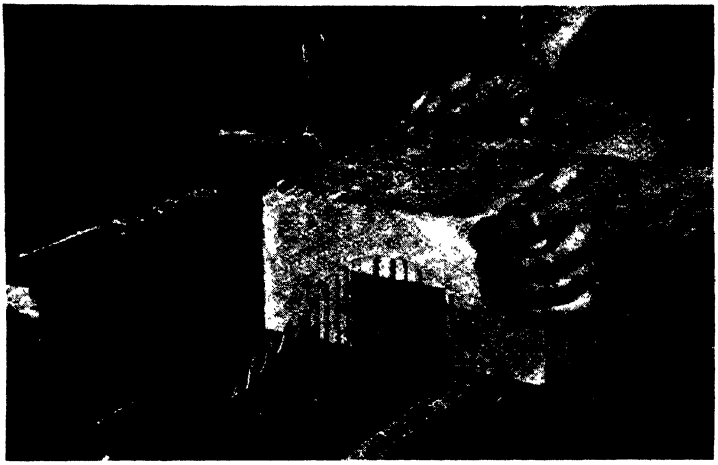


FIG. 26.—CUTTING A HALF-ROUND COREBOX ON A CIRCULAR SAW

Cutting the Corebox on a Circular Saw

It is essential that the circular saw to be used on this job has a "rise and fall" table, so that a number of cuts of varying *depth* may be sawn. Before putting the saw-cuts in for the core-hole, if the corebox is made parallel in width and the amount of material kept exactly equal on each side of the centre line, it will be found that by turning the corebox round and working from *two* edges, each setting of the machine is good for two cuts to each half-corebox (four in all). This method may sound a little long-winded from the production point of view, but in practice is found to be very greatly time-saving. Further, by reason of the straight-line sawcuts the truth lengthwise is easily assured, which is not so when cutting a long half-circle by gouge (Fig. 27).

Special Machinery for Cutting Coreboxes

The "Universal Pattern-miller" is probably the most versatile machine in use in the modern pattern-shop, and Fig. 28 shows a high-speed method of cutting a valve-body corebox by the employment of form-cutters on an adjustable revolving head which lowers into the roughly built-up block and immediately performs accurate semicircular shaping.

The use of modern machinery, however, does not in general affect construction of patterns and coreboxes from the viewpoint of building up and sound mechanics. Only occasionally is it desirable to slightly modify grain arrangement for purposes of obtaining better finish, otherwise it may be taken that over the majority of work a job constructed and arranged for hand methods of cutting may be at once switched on to a machine.

Turning Concave Ends

Many coreboxes have ends which are concave. Also there are frequent calls in various types of pattern-making for, as an example, two half-domes, or, say,

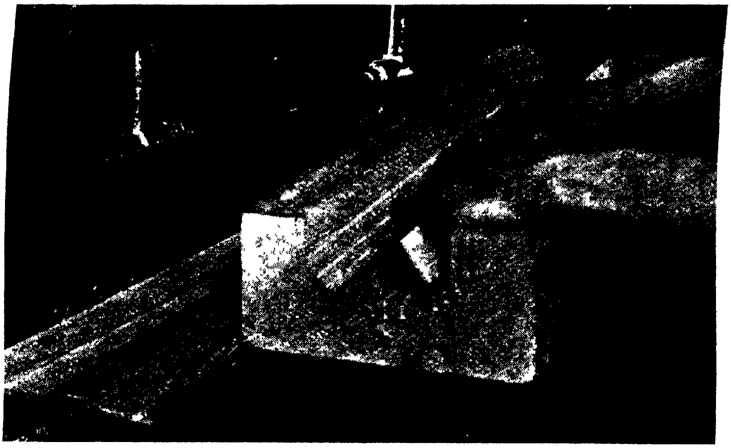


FIG. 27.—MAKING HALF-ROUND COREBOX

Breaking away the pieces left after saw-cuts have been made for half-round hole in the corebox.

two half-bosses. The main thing to watch in making semicircular jobs is, of course, that they are a true radius, and also that when both halves are to be used, each half is an exact one.

The most common system of turning half-circular parts is that of screwing the two pieces on to a chuck, each piece held individually. This method is quite satisfactory for general purposes, but always there is centrifugal force which tends to open the joint of two pieces being turned in that way with the consequence of obtaining two half-round parts neither of which is true to radius. The usual method of preventing such occurrences is to drive a dog across the two parts, but another satisfactory way is to glue the two parts together with a piece of paper between the joint.

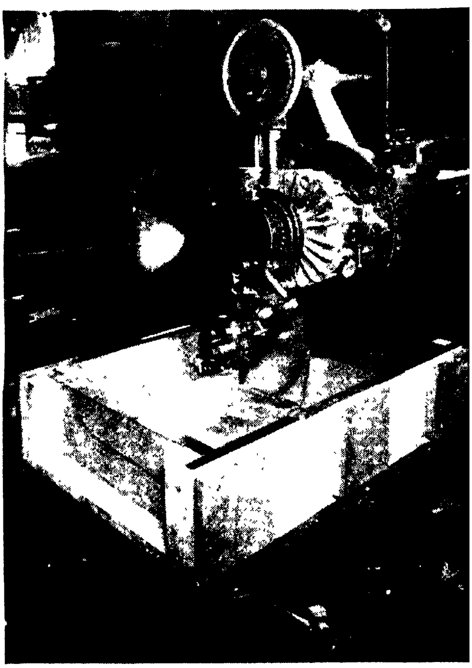


FIG. 28.—VALVE-BODY COREBOX BEING CUT ON PATTERN MILLING MACHINE

Paper Jointing for Glued Joints

This paper jointing will be found very useful for all kinds of jobs, as it enables the glued joint to be very easily split apart, while at the same time holding quite securely for most working

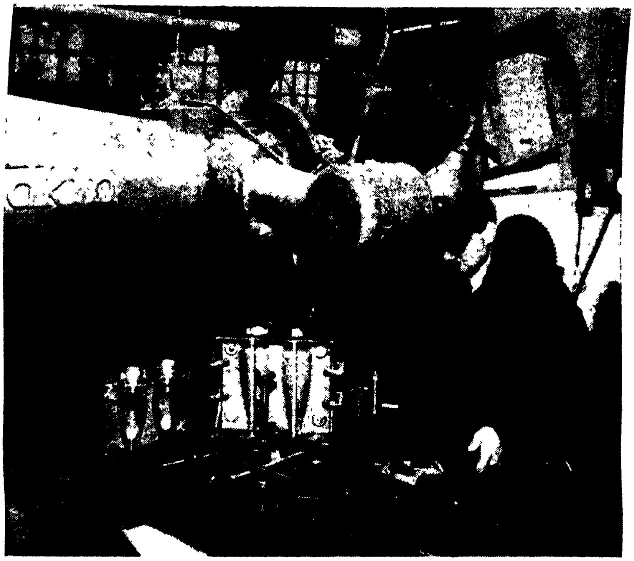


FIG. 28A.—PATTERN-MILLING MACHINE
Showing milling process on conical holes.

operations. When using this system, just apply the glue in the usual manner to both faces of joint, and lay the paper on one face, then quickly press the other glued face on top and allow to set firmly.

How to Make Round Coreboxes with "Chambers" or "Steps"

A piston corebox can be seen in Fig. 29. In most cases a round-cored hole where a corebox is required has varying diameters or else some projections. Founders are able to "strike up" in loam most standard-size round cores.

The method most used in production shops is to make a separate piece for each different diameter. For example, a corebox with one step of, say, 2 in. diameter and 4 in. long, widening out to 2½ in. diameter for a further length of 2 in., would most accurately be made in two units (for each half-corebox), the joint being made at the step (Fig. 29). A skilled pattern-maker would not use this system on a simple stepped corebox, but for ensuring a true circle at all points this method is the best.

Certainly, when making a corebox, and on occasion patterns with a great number of circles struck from a common centre, but of varying diameters, the system of building up a layer for each change of diameter gives accurate results, making a clean-cut job.

There are also a number of other facilities in this method. For example, Fig. 29 shows a corebox with an unusually shaped chamber and the ends *square*. Bosses arriving in coreboxes of this nature are easily marked and cut in their true position, it not affecting the style of manufacture when the core happens to be partly square, round, or any irregular shape. The most important points

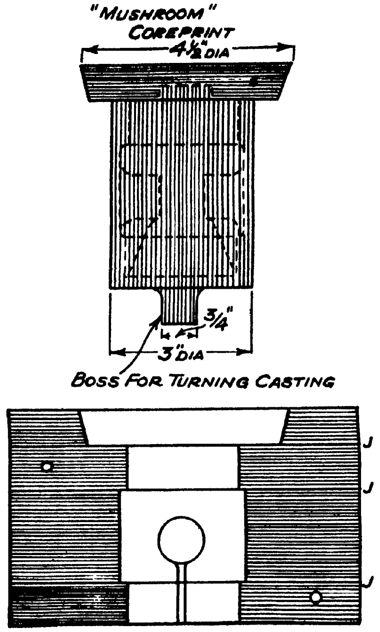


Fig. 29.—Piston; shaded lines show direction of grain of each piece

Note the spigot for centring the mushroom coreprint on pattern. The corebox is made of pieces jointed at *J* to facilitate manufacture.

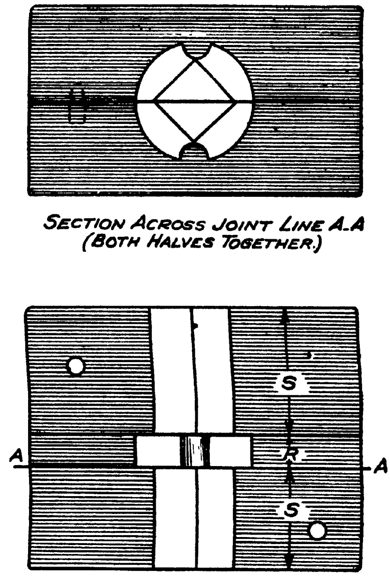


Fig. 30.—Making up coreboxes

Showing how the making up of pieces enables coreboxes with difficult recesses to be easily cut with positive accuracy, regardless of shape or extreme changes in sections.

to watch are, *first*, that when assembled all the holes are on the same alignment as when marked out; *second*, that when finished the corebox is quite rigid, particularly across the joints.

The first point is overcome by screwing all the layers of pieces together in their correct final positions and marking out centre lines, etc. While still assembled, the *outside* edges of the box may be trimmed, which will give a further guide for alignment, and if a further precaution is desired, a long wooden dowel may be inserted right through the assembly. This latter is quite advantageous from the strengthening point of view as well, although the most used method is to screw a batten on the back of each half-corebox after it has been cut, assembled, and cleaned up.

"Mushroom Coreprints"

Overhanging coreprints are called by this title. It means that the print is larger than the opening, and *also the pattern* or outside of the casting. Used largely on pistons, the features of this type of print are that the core is balanced and registered with a minimum of space as applied to corebox and moulding

box, and sand which is for core-stay only. Almost any casting which is "blind" at the opposite end of the opening used for the coreprint, such as an ordinary piston, lends itself to the favourable use of the overhanging coreprint. Frequently, too, the application of this type of print facilitates the easy moulding of a casting which would otherwise be impracticable (Fig. 29). Instead of the usual system of the core being, so to speak, *"pegged"* into its position by the aperture left by the coreprint, the core *rests* upon the ledge made by the overhanging print.

The principal points to watch when using the "mushroom coreprint" are, that the thickness of the print is sufficiently heavy, and the edges are well tapered. The amount or width of ledge is not so important, as a relatively small shoulder or ledge will support any weight providing the material allowed in thickness is sufficient.

Balance Coreprints

Occasions arise when a pattern is required for moulding in a particular way and does not lend itself favourably to the usual method of arranging coreprints or that of the "mushroom" type. Taking a water-valve casting as an example, in types frequently occurring there are two cores with only one opening for one core and two openings for the remaining core.

Use of Chaplets

It may be known to some readers that the foundry can support unbalance cores with studs inserted between core and mould, which are called "chaplets." This measure, however, is more in the nature of an emergency rather than good practice, hence especially on jobs which have to withstand a specific pressure of water or the like, cores are made to be self-balancing, thus ensuring a sound casting.

Using Balance Coreprints

The type of print most used is one which has a short length of positive size core enlarging out to a size which is equal in cubic contents to that of the internal core. Great care should be taken to ensure that the whole of the coreprint is a neat fit into the corebox. (This precaution is always advisable with any print, as rapping pattern in moulding and core in extracting makes a slight difference towards the end of loosening the fit of core into the mould.) Nicely fitting cores are essential in obtaining accurate castings, and these points help to that achievement, especially where one print only is responsible for holding the core.

Finally, another advantage in using the type of balance print described is that the shoulder made by the enlarged portion serves to guide the moulder in placing his core in its correct position, and keeping it there without nailing, this being necessary with an ordinary length of straight coreprint.

Using Templates

Irregular sections of patterns and coreboxes are at times difficult or impossible to mark on the job, to enable true cutting. At these times templates made

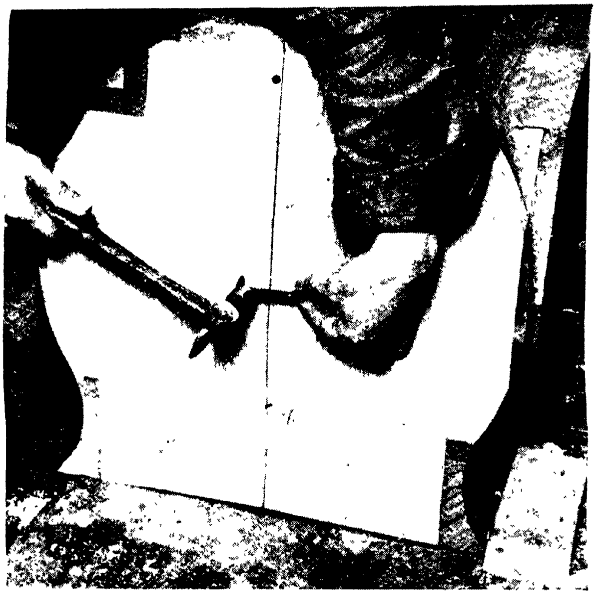


FIG. 31.—USING A DOG TO HOLD THE TWO HALVES OF A PATTERN TOGETHER
Note that this job would not be practicable for cramping.

in the proper way serve the purpose. The first rule is, always work from a common base-line, i.e. if a corebox, work off the joint or face of half the corebox and likewise with the pattern. Where the pattern happens to be solid and the centre line not positive, endeavour to work the template off the most positive points or faces.

Scribing Block in Use

Actually, centre lines should always be marked very accurately on the pattern or corebox, and the best way in most cases is to use the "scribing" block or surface gauge.

A Common Error

When using this tool, although the job may be set up on a surface plate and angle plate, a common error is that the *face* or joint is not *square off the surface plate*. Sometimes this is due to the job not being parallel, and/or the face which is up against the angle plate being smaller or not flat. A safety precaution for all these possibilities is to keep a square set against the face of the job all the time the "lining out" is being marked (Fig. 32).

BEDPLATE PATTERNS

The design of bedplates varies so greatly that we will just generalise on the small and large jobs, giving cases that are frequently occurring.

At all times study should be made of the number of castings likely to be taken off the pattern, and the faces where good metal is required for machining, which will mostly determine whether the pattern will be cored or "leave its own."

As already mentioned, coreboxes can be used for the purpose of keeping a light pattern a strong and solid one, besides facilitating moulding, although the pattern could mould without core. This is particularly applicable to bedplates.

Small Bedplates

The reader can form his own idea of the way that small bedplates should be made from the description given previously of terminal-box patterns (cored). It will also be found frequently advantageous to use mushroom coreprints.

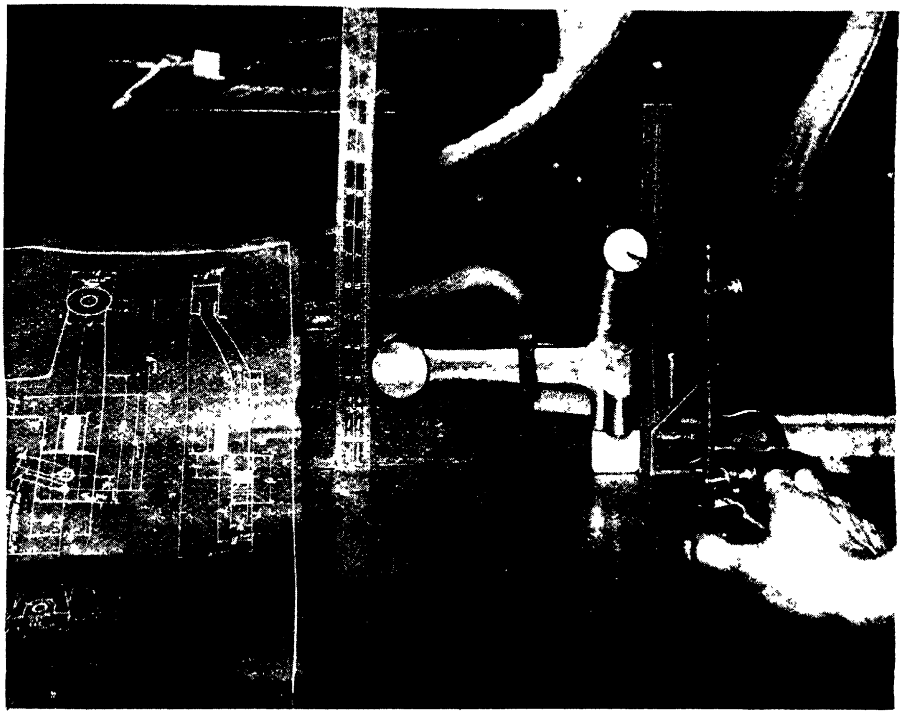


FIG. 32.—LINING OUT A METAL PATTERN
Note square at edge (which should be perpendicular) as check. All horizontal lines should be marked in the one setting up as far as possible.

How Large Bedplates are Made

Large bedplates, say from 2 ft. by 12 in. upwards to any size, are usually made as follows: a main plate is prepared which, although it may comprise a number of boards, need not be glued at the joints. Rather is it best to allow a small gap of approximately $\frac{1}{8}$ in. (one-eighth) between joints where the after-cutting and working of the pattern will permit. Prepare all the ribs and sides for screwing to the main plate. Then when a very large job is being made, and the main plate comprises a great number of boards, a temporary pair of battens may be screwed across the whole in order to hold them for marking out. Alternatively, if large cramps are available, these may be used, but are not so satisfactory, as a tendency for buckling, and boards shifting, often arises if the job has to be moved for any reason. One straight and true edge should be kept outside for squaring off lines and using as the main working edge. When squaring off lines at right angles to this edge, a test of truth is easily made by using a stick of any convenient size which will span corner to corner from a line at or near each end of the plate (Fig. 33). Watch carefully that both opposite

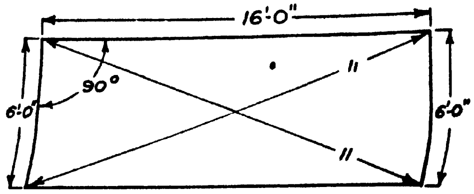


FIG. 33.—HOW LARGE RECTANGLES ARE CHECKED (BEDPLATES, ETC.) FOR BEING SQUARE

The distance diagonally one way should be marked on a stick of suitable length, then tried across the other way to check equality.

lines are parallel one with the other; then having ascertained this, the distance diagonally across both corners should be exactly equal.

When a square line has been marked at each end of the plate, all further lines required should be measured off these former two, as any small inaccuracy along the working edge will throw the square out of truth considerably, giving much trouble when the job is advanced and points are checked against one another.

Fixing Ribs

Once the main plate has been marked out, it is not advisable to move it in any way until a number of ribs and/or sides have been affixed, sufficient to hold the whole job permanently tightly true. A dab of glue on the joints is a good help towards this effect, and relieves the tendency to "racking," i.e. a push at any one corner being enough to make corners unequally apart (*see* truth test).

When working on a pattern which has an uneven outline and/or a number of parts which require the plate to be cut away, if difficulty can be seen in cutting the plate after all the webs have been affixed, the particular board or boards where this separate cutting is necessary may be taken apart from the main plate and worked individually, but it is best always to allow a little for cleaning up the whole job when finally fastened together.

Rigidity and Strength of Pattern

Perhaps the most important point about large bedplates is the rigidity and strength of the pattern. Usually designers arrange webs which automatically make this effect strong, but even so, if the pattern-maker is too intent on simplifying his own job, the result is apt to be weak in the places where strength is essential. Therefore keep longitudinal webs in one length and avoid butt or short-grain joints at the centre of the pattern should a straight-through web not be in the design (Fig. 34). When the last-mentioned design is being worked, and the webs are in most cases "set" or out of alignment as part of the actual design, do not build the webs on, as on an ordinary straightforward job, but make each web that has a "set" separately and ensure that each is self-supporting and strong at the joint. It is not necessary to give any particular method for the latter joint, as the design of the job in hand usually makes obvious the best and most practical way, and in this instance, so long as the joint is strong it matters not whether it is screwed, halved, or spliced.

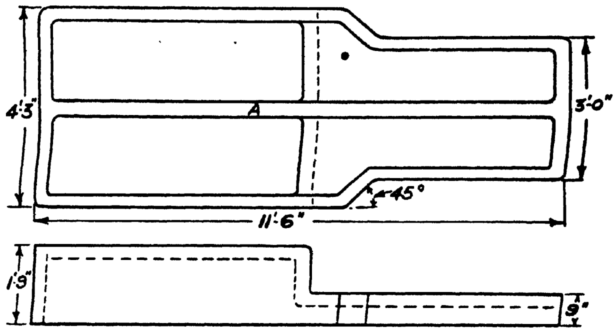


FIG. 34.—BEDPLATE OF UNEVEN CONTOUR
Rigidity and strength in a pattern of this type is helped by making centre web *A* in one piece and outside webs made up independently from the pattern.

Webs and Beads following Rounded Corners

On a large proportion of patterns, especially bedplates, a web or outside rib is arranged with a large rounded corner which is often a weak point in a pattern (Fig. 35), particularly when the pattern is made to leave its own core. Generally speaking the job can be considered passable if a wood fillet is glued in the inside corner and the outside corner radius does not cut the original square-edge joint away (Fig. 35).

The pieces glued in the inside corner should always be "long" grain as illustrated, as not only does this hold best, but gives best results on "feathered edges," i.e. where an added part is cut down to die away into the existing job. Also there is the "draw" on the sand, which is harsh when working *across* grain in moulding.

Another system which is occasionally used on very large rounded corners, where strength is particularly desirable, is that of fixing a block in the inside corner rounding off the outside radius, but not cutting away the inside to suit. The inside radius is then either cored away by making a suitable corebox, or, where not desirable, a piece of web made separately which the moulder places in the sand and uses to "stop-off" the space otherwise filled by a core.

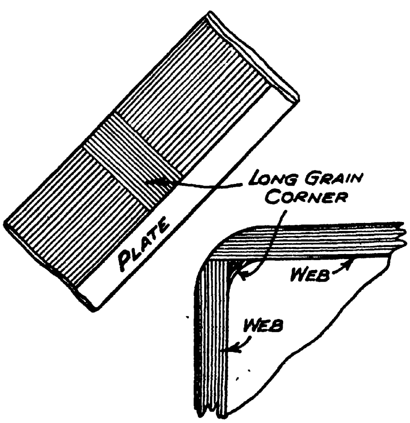


FIG. 35.—WEB FOLLOWING A ROUNDED CORNER
The fillet glued in should be long, straight grain, regardless of the shallowness of the web or bead.

Stopping-off Parts of Patterns and Battens, etc.

To make patterns of light structure a flat and rigid job, it is at items necessary to add a "batten" or "stopping-off" piece. There are a large number of uses for "stopping-off" different parts of patterns when moulding, and the most

common is as applied to extra parts which pattern-makers add for constructional purposes. Battens or similar pieces should as far as possible only be added to straight surfaces, or such that are easy for the moulder to make good in sand, and should be kept well clear of any bosses, etc., on the pattern. Liberally taper all such pieces and always *screw* them to the job. The sharp corners should be chamfered off, which gives the clue, apart from not painting, that the batten is not to be cast.

Eliminating or Reducing Timber Shrinkage Effects

A glance at Fig. 36 will show how the pattern-maker, when faced with a large area proposition, reduces the possibility of dimensional errors through shrinkage and so on, by constructing his pattern of a *number of narrow-width pieces*, each being held *in situ* by a suitable rebate or groove. The illustration is that of a mould plate pattern for forming corrugated sheeting, and the narrow pieces having had the semicircular groove cut therein, are, after assembly, rounded off to complete the shape. The *centres* are thus held true and over-all width and length maintained. Further applications of this method of construction will be quite obvious for similar patterns which cover a large area.

Moulding Formers or "Ram-up" Blocks

Where a light pattern of uneven section has to be made to mould without coring, one obstacle is that of maintaining the correct outline while the pattern is in course of moulding. Battens (as previously dealt with) are not suitable for uneven surfaces, and the alternative is a former which takes the shape of the internal or hollowed-out side of the pattern. Patterns for ornamental and stove castings are frequently adaptable to this system, which gives support to the job whilst the sand is rammed around it. Further, by making the former or "Ram-up" block as a preliminary to the pattern, and by fitting the pattern to that former, a large number of templates may be obviated.

PLATE MOULDING

When Plate Patterns are Required

The mounting or fixing of a pattern to a plate reduces the skill required in moulding a pattern, as no joint or parting is then required to be made by the moulder. Patterns which are made in halves are readily adaptable to plate moulding, provided the joint or meeting faces of the two half-patterns is flat and not broken up by any "stepped joints" or undulations. Should a pattern for any particular reason necessitate a joint of uneven character, a special plate may be made to accommodate such pattern, and in extreme cases a special shaped moulding box may also be provided to match the shape of the plate (Fig. 37) mortised together, and the "filling-in" boards also mortised through the framework (Fig. 38). A bad policy is to make the plate before consulting the founders on the dimensions of the moulding box which is to be used. The success of plate moulding an intricate job depends to a large degree on the accuracy of the pin-holes which locate the two halves of the moulding box, and also the plate.

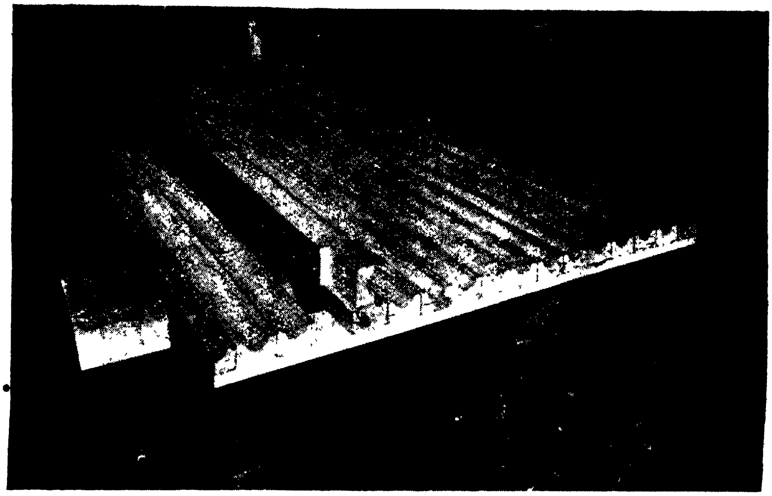


FIG. 36.—NARROW PIECES HELD TOGETHER BY CROSS MEMBERS HOUSED IN REBATES OR GROOVES HOLD THIS 8-FT. BY 4-FT. MOULD PATTERN DIMENSIONALLY CORRECT AND FREE FROM WARP OR SHRINKAGE BY THE TIMBERS

The Joints to Use

Teak gives good service on plates, but a good spirit glue is necessary to hold to this greasy-natured wood. "Secret" or "slot" screwed joints are sometimes used (as previously described in loose-sole plane design). The writer advocates a tongue and groove as being as good as anything on general plate construction.

Wood plates are not suitable for shell-like patterns which require a good part of the plate to be cut away to accommodate mounting.

Construction of Plate Patterns

Where it is proposed to use both sides of the plate for mounting patterns, a wood pattern, if used, should be protected at points likely to receive wear and also in places which take the weight of the whole job, when it is placed aside. The most common method of protection is that of making the hardwood pattern first, then small parts in softwood representing the corners of bosses (which receive the wear) off which a brass casting is taken and then filed and fitted to the hardwood main pattern. Pieces of sheet brass $\frac{1}{16}$–$\frac{3}{16}$ in. thick are also employed to edge and face parts likely to receive excessive wear. Wood patterns of any *solid* type can be made adaptable for "plating" providing

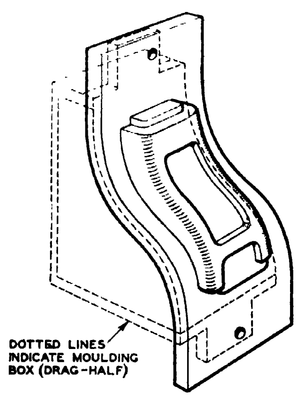


FIG. 37.—A CURVED "END FRAME" PATTERN MOUNTED ON SHAPED PLATE FOR USE IN CONJUNCTION WITH A SPECIAL MOULDING BOX

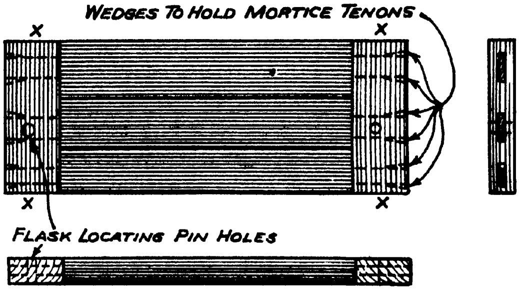


FIG. 38.—CONSTRUCTION OF A PLATE FOR PLATE-MOULDING PATTERNS

The end stiles should be left longer than required finished, at *X*, to support grain when tapping in the wedges.

that plenty of taper is allowed and the base made up flat by coring (if necessary).

Gates of Patterns

The expression "gate of patterns" must not be confused with "the gate" which founders make when cutting the mould to allow the metal to flow into a mould. The former term applies to two or more patterns which are exactly identical, joined together by a small additional piece, which idea is to facilitate production in handling *small* parts. When making a gate of patterns, each one can be made as a separate job, and the whole joined together by strips when finished.

Fig. 41 shows a typical gate of four patterns which has been made in this way, and the rule held across them shows how straight the moulding lines should be arranged, which saves the founders much time in cutting the joint line of the mould.

Applying "Heads" to Patterns

On jobs where the engineers require exceptionally good metal (such as cylinder blocks, etc.), the founders mostly cut their own "heads" or "risers" in the mould, which take up the flow of bad metal and allow the entry of good metal into the mould. At times, however, the pattern-maker has to allow an additional lump to his pattern to save the moulders this time. Fig. 40 shows a typical "head" designed to facilitate removal after casting.

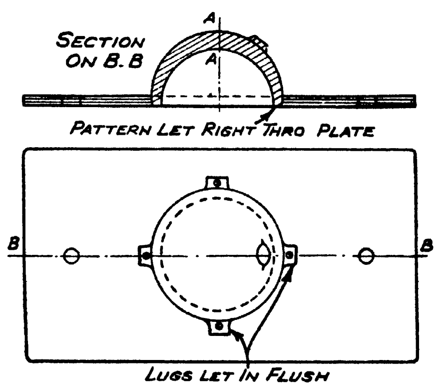


FIG. 39.—BRASS PATTERN OF A DOME ON METAL PLATE

Both sides of the plate are used, and the metal pattern has the thickness of the plate added to its metal, which is added *vertically* (accounting for greater noticeability at *AA*).

STRICKLE BOARDS

The complete use of strickle boards comes under foundry practice,

FIG. 40. — A TYPICAL HEAD

The part *C* denotes the actual casting required, while *H* is the extra pattern addition for head, which is intended to take the flow of bad metal and permit of only best metal in the part used.

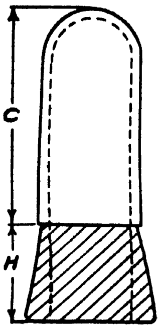


FIG. 41.—THE STRAIGHTEDGE BEING TRIED ACROSS THIS GATE OF FOUR PATTERNS INDICATES THE POINT OF KEEPING EASY MOULDING LINES WHEN ARRANGING THE INDIVIDUAL PATTERNS FOR ONE UNIT

although pattern-makers make them. The equipment and methods of an individual foundry govern the extent to which strickle and *loam* work can be applied. Space does not permit of full detail in strickle work, but briefly the common uses are boards for "turning" cores, boards for spindle mounting, and boards of the "template type," used in conjunction with a base and end pieces attached. Fig. 42 shows an example of core and the board for striking it. The circles cut in at each end of the board indicate *the diameter of the core at that particular point*. The strickle board has a contour that follows the outline of the desired core when working off the diameters marked at each end of the board. These circles should be marked on the side which has the bevel, this being the way up in use.

Striking up Half-circles

A board is prepared, say 3 in. wider and longer than the diameter of the core to be made. A half-circular piece representing half-circle of the core is screwed at each end, the face being put on in line with finished length of core.

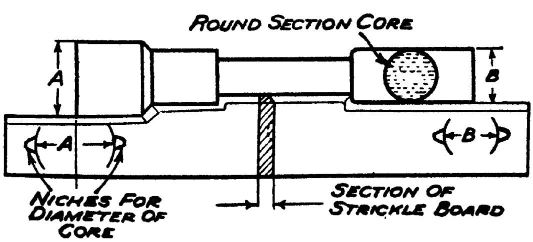


FIG. 42.—HOW A ROUND CORE OF VARIOUS DIAMETERS IS STRUCK IN LOAM-SAND

Showing the strickle board in position against its core. The diameter at each end, *A* and *B*, is marked by cutting a niche at the places shown.

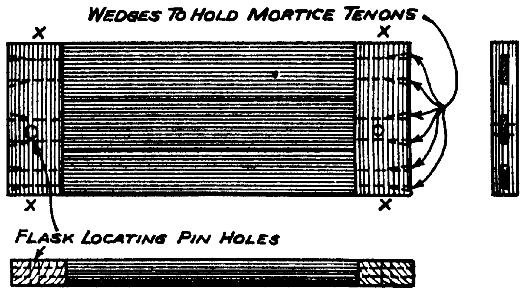


FIG. 38.—CONSTRUCTION OF A PLATE FOR PLATE-MOULDING PATTERNS

The end stiles should be left longer than required finished, at *X*, to support grain when tapping in the wedges.

that plenty of taper is allowed and the base made up flat by coring (if necessary).

Gates of Patterns

The expression "gate of patterns" must not be confused with "the gate" which founders make when cutting the mould to allow the metal to flow into a mould. The former term applies to two or more patterns which are exactly identical, joined together by a small additional piece, which idea is to facilitate production in handling *small* parts. When making a gate of patterns, each one can be made as a separate job, and the whole joined together by strips when finished.

Fig. 41 shows a typical gate of four patterns which has been made in this way, and the rule held across them shows how straight the moulding lines should be arranged, which saves the founders much time in cutting the joint line of the mould.

Applying "Heads" to Patterns

On jobs where the engineers require exceptionally good metal (such as cylinder blocks, etc.), the founders mostly cut their own "heads" or "risers" in the mould, which take up the flow of bad metal and allow the entry of good metal into the mould. At times, however, the pattern-maker has to allow an additional lump to his pattern to save the moulders this time. Fig. 40 shows a typical "head" designed to facilitate removal after casting.

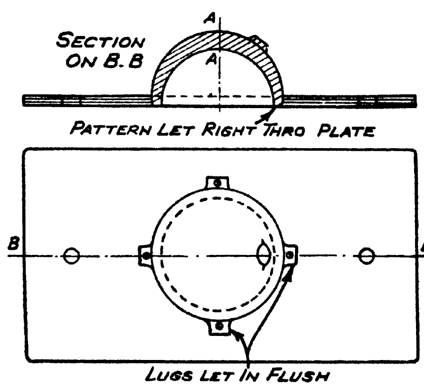


FIG. 39.—BRASS PATTERN OF A DOME ON METAL PLATE

Both sides of the plate are used, and the metal pattern has the thickness of the plate added to its metal, which is added *vertically* (accounting for greater noticeability at *AA*).

STRICKLE BOARDS

The complete use of strickle boards comes under foundry practice,

and drilling machines which are most valuable and inexpensive time-savers to the pattern-maker, besides assisting towards better finish.

Combined planing and thicknessing machines, disc-and-bobbin sand-papering machines, routers, trimmers, and cross-cuts are all good heavy-duty equipment for pattern-shops engaged in large-scale construction of wood patterns. In the section following on *metal* patterns will be found comments on specialised machinery for the up-to-date *metal* pattern-maker.

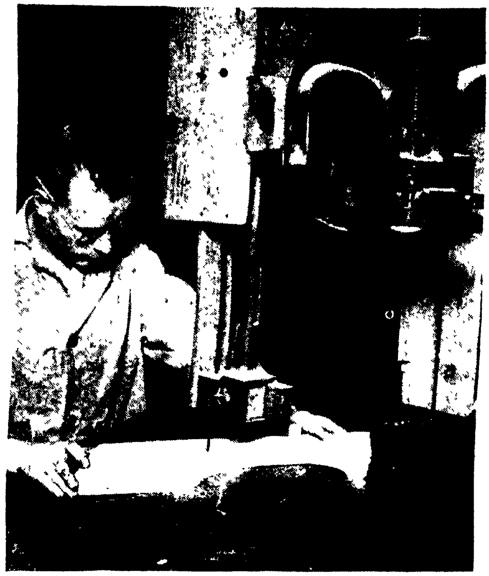


FIG. 44.—BANDSAWING AN ANGLE OUT OF SQUARE BY THE USE OF A CANTING TABLE

FINISHING PATTERNS

The life of any pattern is prolonged if fitted with suitable rapping plates or lifting straps, besides assisting the founders to handle the job readily and easily. Metal dowels are also an asset to a split pattern or corebox, as they do not become "sloppy" in fit as quickly as wooden dowels, thus ensuring a casting without the heavy joint mark which frequently does occur. These accessories can be purchased at any pattern-shop supplier.

Using Leather Fillet

Leather fillet is a good feature in patterns where radii cannot be worked out of the solid wood, but greatest care should be taken to wipe superfluous glue away from pattern *and* fillet, preferably with a wad of damp shavings. Thoroughly sand-paper fillet when dry and drive in a few

FIG. 45.—PLANING THE BEVEL ON A LAG BY MEANS OF ADJUSTABLE FENCE ON PLANING MACHINE

FIG. 46.—APPLYING LEATHER FILLET TO A PATTERN
The "rubber" should be twice the radius of the fillet used, i.e. the diameter of a piece of dowel would be ½ in. for ¼-in. radius fillet.

pins to hold fillet in case glue perishes—this invariably happens to patterns in constant use (Fig. 46).

To preserve the Pattern

Finally, to preserve the pattern, make it smooth to mould easily, and keep out dampness from the sand, shellac varnish or "button polish" is applied. The first coat will bring up the grain of the wood, which must be sand-papered when dry—the process known as "rubbing down." Nail holes, etc., may then be filled with putty or hard shellac or plastic wood, and a second coat applied. This process, when repeated a second time and the third coat applied, should give a finish suitable for most work.

Colouring Patterns

Three colours are now adopted as standard for use on patterns in Great Britain (see B.S.S. 467—1932). Into separate pots of the "button polish" a little spirit black, pure vermilion or vermilion substitute, and yellow ochre may be added and applied with a soft brush to the pattern as follows:

Patterns for Cast Iron and Steel Foundries:
Red coreprint, yellow machined faces, black remainder.

Patterns for Aluminium, Brass and Non-ferrous Metals generally:
Black coreprint, yellow machined faces, red remainder.

Where a pattern is for castings to be finally machined all over, the all-black or all-red colour may be used (to indicate ferrous or non-ferrous) and the wording "Machined all over" painted or stamped on the pattern.

Use of "Rubbing Sticks"

As many instances occur which present difficulty in papering to a good finish, the use of a rubbing stick *shaped to follow* the contour of the job will be found a great asset.

At this juncture it is well to emphasise that *sharp tools* are the first important factor, and sand-papering, etc., only a secondary in keeping the grain of the wood from appearing on the casting.

GENERAL POINTS WORTH NOTING

"When in Doubt—Set the Job out"

In other words, if a pattern-maker becomes a little hazy as to the construction of a pattern or a dimension does not work out right, he should mark the job on a board.

Don't be "minute wise and hour foolish"—be sure of your size *before* cutting.

Prefer a core to a loose piece if coring is at all practical on a pattern.

Be as generous as possible with taper in all cases where limits are not essential.

Marking Wood

A sharp thin knife is better than pencil for marking out wood patterns, giving greater accuracy, and preventing "breaking down" of edges when actually cutting the woodwork into shape. False lines may be erased by applying water.

Fix rappings and lifting attachments where the least damage and moulding inconvenience is likely to occur, preferably in coreprints or blocks.

Take care with your drawing. Mistakes often occur through a fold obliterating a figure or line and part of the drawing being torn away, causing waste of time.

Study the Founder's Methods

Founders differ widely in their equipment and method of handling particular castings; the manner in which a pattern is constructed, made to mould, cored and "parted" being dependent on, firstly, the number of castings required, and secondly, the equipment the foundry propose to bring into service. Co-operation between founder and pattern-maker is sound engineering, as each can help the other to overcome economical and practical difficulties.

Good Results from Patterns

The pattern-maker will frequently be called upon to make a "one-off" job. Naturally such a pattern will not stand up to wear, nor give the class of casting that a mahogany or first-class metal pattern will permit; therefore first cost is likely to be a misleading factor in this initial but all-important stage of engineering work.

Patterns moulded in "Cement Sand"

Generally speaking, there is no fundamental difference required on patterns moulded in "cement sand" as compared with the familiar black or "green" sand.

Extra attention should be given to coreprints and coreboxes to ensure easy placement of cores in the mould, and a small fillet worked in corners where prints join pattern will help to overcome cracking moulds.

Loose pieces, where used, should be as light as possible, with particular reference to metal patterns, it often being found necessary to substitute wood

loose pieces in place of metal, as the latter have a tendency to drop out of the sand mould merely by their own weight, thus breaking the mould or damaging a delicate section.

Almost any kind of pattern used in the stand methods of "old" type sand can be employed in cement sand, but best results are obtained from "split" patterns, i.e. the types which permit of *plate* moulding.

GENERAL NOTES FOR MAKING METAL PATTERNS OF ALL KINDS

A good many engineers think of *wood* when they think of patterns, without realising that a pattern made of a suitable *metal* very often pays for itself over and over again, not merely because it will last longer than wood, but because faster production can be obtained, together with cleaner castings, more sharply defined detail, and constancy, without the inherent delays and errors frequently brought about by necessitous repair, as is so often met with when using a wood pattern beyond its fair life.

Even where a comparatively small number of castings only may be required, a metal pattern should be considered if it is desirable to maintain great accuracy from time of storage whilst the pattern is not in actual use until re-entry into the foundry, or if cores can be eliminated by making a "shell" pattern in metal, which in wood must, by reason of light thickness of material, be too weak to hold up to the ramming of a mould.

How much Machining is Necessary?

While many metal patterns are best machined, it is not always necessary to have a metal pattern machined all over. If a good clean casting is obtained, filing, scraping, and grinding gives quite good results, and no allowance of extra metal for this operation is required (the amount taken off is so small that castings frequently gain that in the rapping process).

Selecting the Metal to be Used

When the pattern-maker has to decide on the kind of metal to be used for a particular pattern, the following is a guide. Long slender patterns or such which have a shape that is likely to bend easily are best cast in iron. Heavy, solid block type, in aluminium. Patterns small but with light sections and many bosses are best in brass or gunmetal. Contraction rules are obtainable which have the extra allowances required for the making of wood masters for the above. Fig. 49 shows an iron pattern with its wood master and final casting.

"Lining Out" Metal Patterns

Although the wood master-pattern may have been accurately made, the casting to be used for the metal pattern often turns out of the mould with a little discrepancy here and there. It is therefore essential to check centres of bosses, etc., and Fig. 32, page 57, shows a metal pattern being "lined out," which means marking centre lines and checking the general dimensions of the

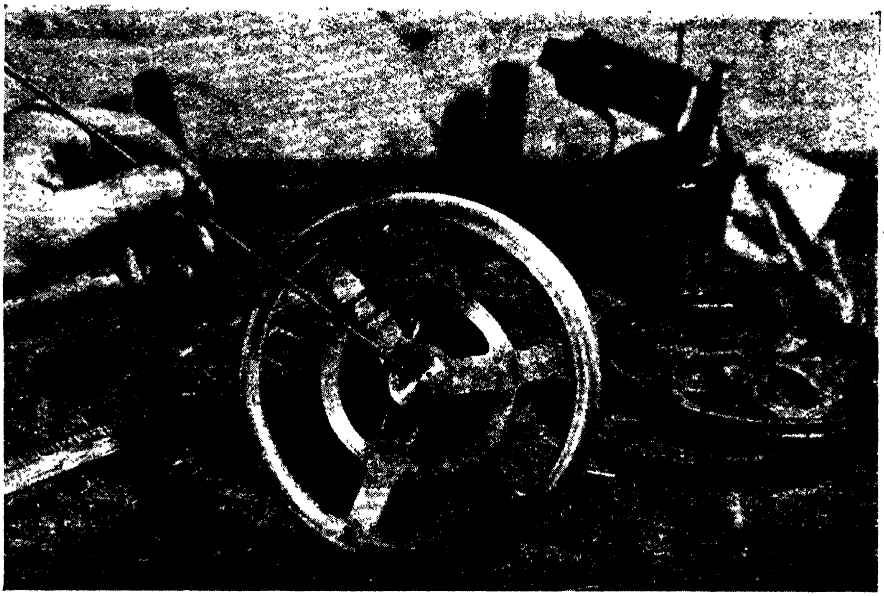


FIG. 47.—INDICATING A "DRAWN" OR SUNKEN PART ON A GUNMETAL PATTERN WHICH IS TO BE FILLED

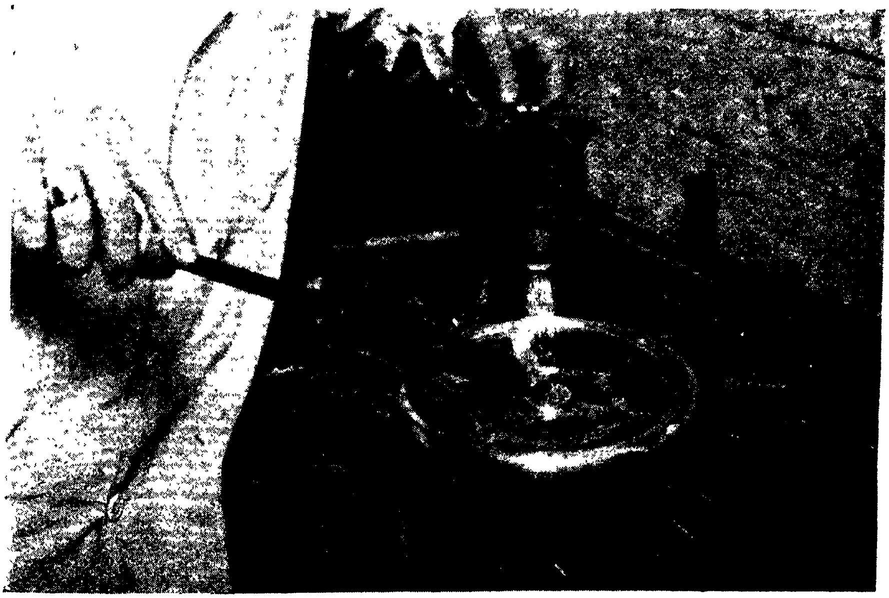


FIG. 48.—FILLING UP A "DRAWN" OR SUNKEN PART ON THE METAL PATTERN BY HOT SOLDERING WITH A PARAFFIN BLOWLAMP

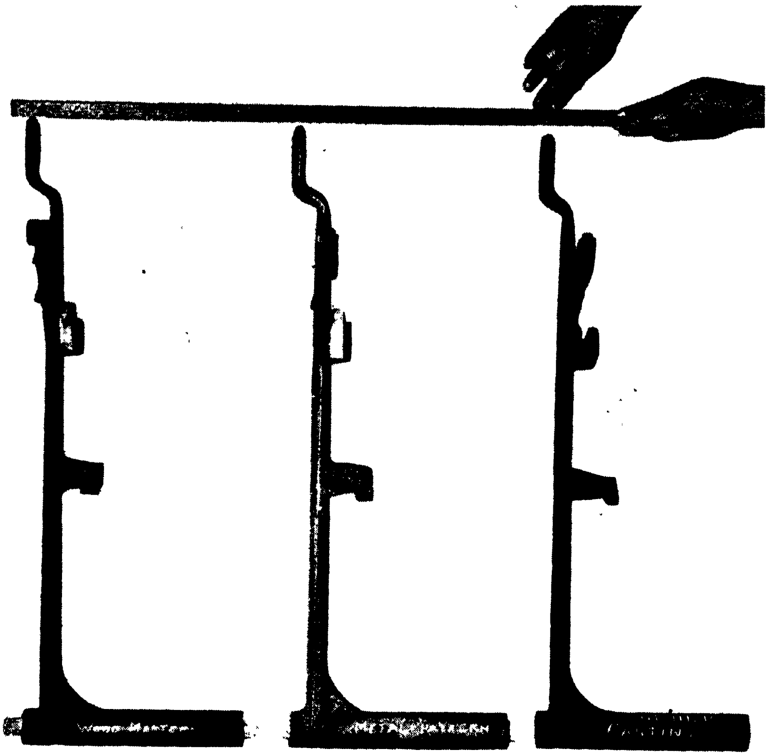


FIG. 49.—THE THREE STAGES OF PRODUCTION WHEN A METAL PATTERN IS USED
Note the considerable amount of shrinkage from the original wood master-pattern to the final casting. (Amount shown by gap between straightedge and jobs.)

casting. It is always advisable to set up the job on a flat surface-plate, and work from a common base line and square edge wherever possible.

Master-wood Patterns

Construction generally would be on lines dealt with in the previous section on "Wood Pattern-making," special care being given to *abundant taper*. Projecting bosses or coreprints to be left off the master-wood and initial casting and affixed after finishing of metal patterns must be left to the discretion of the pattern-maker, who should carefully survey the master-wood pattern before casting, and consider the ease of machining or filing brought about by such elimination (Fig. 50).

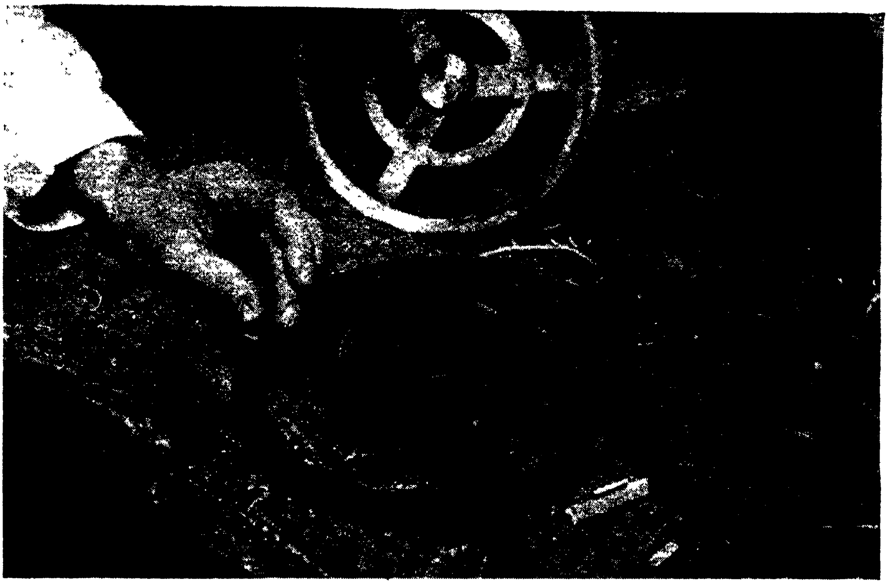


FIG. 50.—A GUNMETAL WHEEL WORKING PATTERN AND ITS WOOD MASTER PATTERN
Showing loose piece cast separate from the main pattern and "sweated" in after turning working pattern.

Procedure for Iron Patterns

For economy on initial cost and the fact that they hold up to a lot of rough usage, iron patterns are now becoming increasingly popular.

Commencing with a *well-finished* master-wood pattern (quality of material and constructional strength being quite unimportant so long as a single good casting is possible), the raw iron casting is obtained which is now to be worked up to a metal pattern.

Distorted Pattern Castings

First examine the raw casting to see that no violent distortion has occurred when casting it. If there is pronounced distortion, it may be best to scrap the casting forthwith instead of attempting costly corrections in metal.

Preventing Distorted Final Castings

Now alter the master-wood pattern to allow *double* the discrepancy and start afresh on a new casting.

The emphasis on allowing double the discrepancy found on a first casting is, of course, only applicable to such as are not caused by bad moulding, and assuming that the foundry is not to blame for the difference in shape or size found between the master-wood pattern and the raw casting for the metal

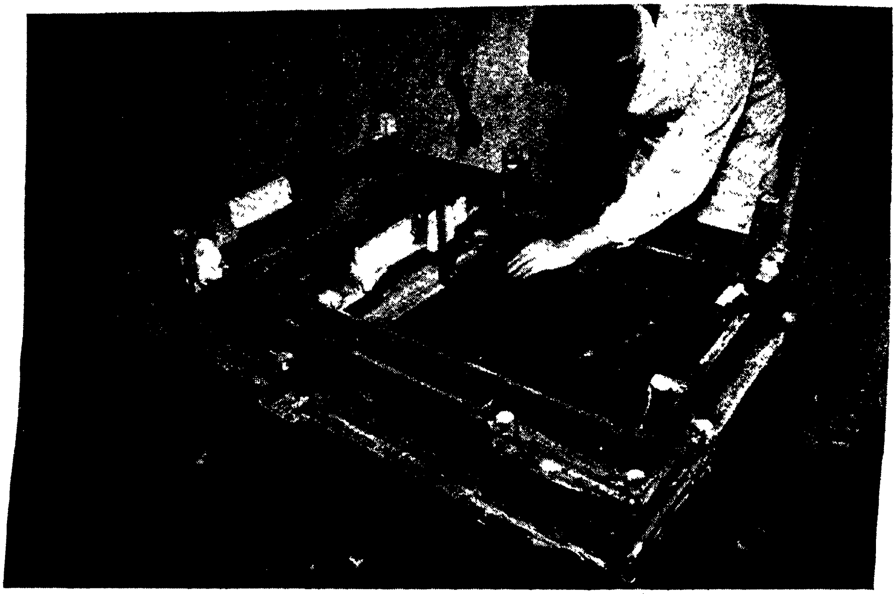


FIG. 51.—LINING-OUT SHALLOW DEPTHS ON A SURFACE PLATE WHICH HAS ALSO BEEN "MARKED OUT" FOR MAIN SHAPE, ENABLING TWO SETTINGS TO BE CHECKED AT ONCE

FIG. 52.—TYPICAL TIE-BARS NOT REQUIRED ON THE METAL PATTERN AND FINISHED CASTING BEING CUT AWAY, HAVING HELD BOTH WOOD MASTER AND PATTERN CASTING TRUE

pattern, we can then be reasonably sure that the same discrepancy will be manifest on production castings.

Here we have, then, a very good "try-out" on patterns that are the actual shape of the finished casting (many will have coreprints, etc., that do not make this test quite so all-embracing).

Basic Lines

Cleaning, filing, or machining a metal pattern should be commenced from a basic line that has been indicated on the drawing. A flat surface that forms a "setting-up face" is best, of course, the only alternative being an important centre line.

Lining-out

No part of metal pattern-making is more important than the "lining" or "marking-out."

A large iron main frame pattern is shown in Fig. 51. This is being checked on two settings by means of a marking-out of the plan shape on the surface plate and the scribing block for vertical dimensions.

This system would perhaps be scarcely accurate enough for the actual machine part, but for patterns is an admirable way of ascertaining accuracy *to a relative* shape or position. The importance of this point cannot really be over-emphasised, as probably nothing gives more trouble in the machine shop than a casting which has been made from a pattern that seems correct when measuring, but which is *incorrect relative* to certain *remote parts.*

Checking

The moral drawn from the above observations is to check as many parts of the pattern as is possible on the *one "setting-up."* Having already illustrated one way of doing this, it will be seen at once that many extraordinary shapes and angles can be "lined-out" and checked by introducing templates and protractor beside the square and scribing block on to the surface plate.

Tie-bars

As one of the most frequent of reasons for a metal pattern is the fragile character of the pattern when made of wood, it is often necessary to introduce a tie-bar or extra section on the master-wood pattern, and this same extra piece is often *cast* integral with the primary metal-pattern casting (Fig. 52). Castings of the shape in the illustration have a tendency to bow at the ends; hence the particular position of the tie-bars on this job.

Small patterns also are often improved by a light tie-bar; for example, a U-shaped piece might have the vertical lines connected horizontally at the extreme tips and thus preserve the parallel. Various designs of light castings that make their appearance to-day will often show call for a tie-bar, even to the extent of casting it in the production castings for the sake of further facilitating machining, quite additional to the moulding.

"Shell" Patterns

Fig. 53 shows two patterns, both of which would be cored to maintain pattern strength if made as working wood patterns, but which are amply strong enough to stand wear and tear of foundry use as metal patterns. In both cases the saving of the core not only means faster production for the foundry, but, more important still, the certainty of *even* and constant metal thickness.

The pattern shown on the left-hand side of the illustration has three lugs just below the open top edges, and whilst the lugs could have been made loose, a core has been placed on the lower part, which helps in this instance to maintain the pattern strength and facilitate easy plate moulding. The pattern shown on the right-hand side is not intended for plate moulding, and would entail an entirely different system of making to be thus employed (see page 51 for appropriate method).

Split or Jointed Metal Patterns

Many small castings, such as valve bodies, pipes, elbow-joints, etc., normally split as wood patterns, may just as readily be split as metal patterns. To make this type of metal pattern the wood master need only constitute one half-pattern, *where it is reversible for its opposite half. This single half-pattern is* hollowed out for lightness and saving of metal (Fig. 54); also a full machine cut would be taken off the joint face of the metal pattern. The two halves as

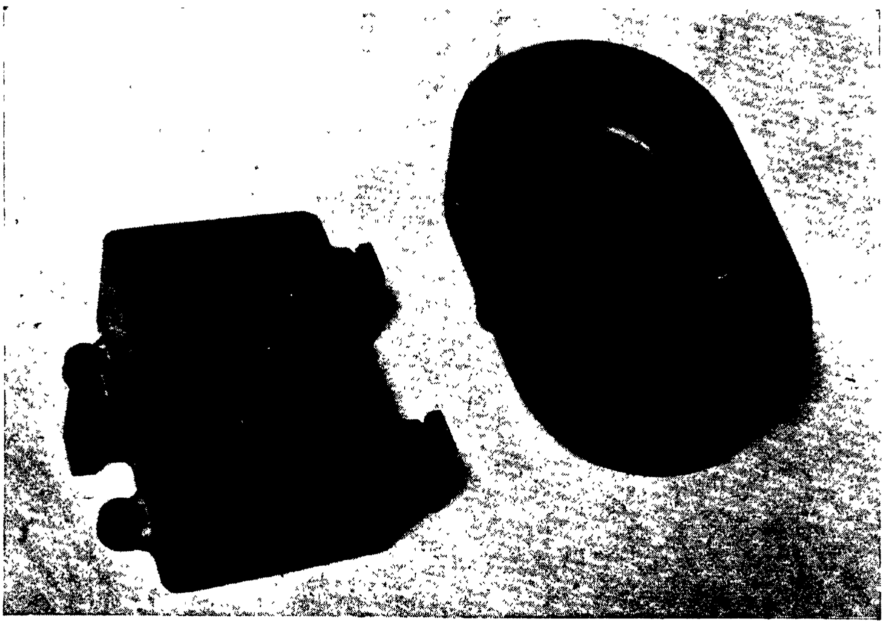


FIG. 53.—*Left*, A "SHELL" PATTERN MADE SUITABLE FOR PLATE MOULDING. *Right*, A "SHELL" PATTERN MADE FOR "LOOSE PATTERN" MOULDING

raw pattern castings would be dowelled and sweated together (if gunmetal or brass) as the first operation after machining the joint face.

Turning the metal pattern in the lathe would then be a single clean operation, and the complete metal pattern would be file finished all over before releasing the "sweated" joint by reheating.

Heavy-type Split Patterns

A main pedestal or column is generally looked upon as far too heavy and cumbersome to entertain as a metal pattern, but actually a machine part of this description can often be made lighter and easier to mould as a metal pattern than in wood. The governing factor is the number of castings required, as metal patterns for very large parts naturally cost more in proportion to wood than small machine parts. In Fig. 55 we show a complicated main column pattern which has been split through a vertical line (now lying horizontal on the work bench). Careful scrutiny of the illustration will reveal that this parting line is "stepped-up" just above the operator's left arm. We learn by this that split patterns may have a joining surface of practically *any* convenient shape to suit the requirements of the job in hand.

Dispensing with Main Cores

To appreciate fully the novelty and merit of the pattern seen in Fig. 55, it must be emphasised that a large majority of pattern-makers would consider it impossible to make such a pattern without a main core where there now is a hollow shell.

Firstly, it must be explained that this pattern moulds as a three-part job—

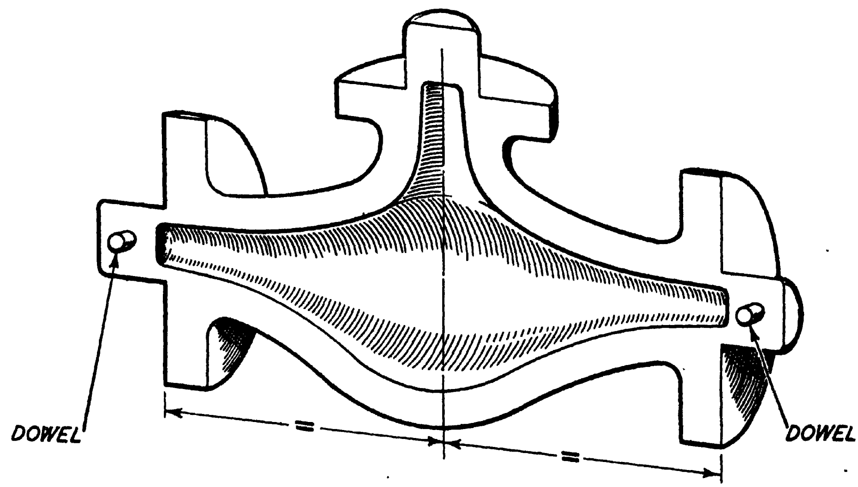


FIG. 54.—ONE HALF OF A "HOLLOWED-OUT" VALVE BODY PATTERN
Showing how joint face is also relieved for even seating.

FIG. 55.—CHECKING ALIGNMENT OF SIDES AND EDGES ON SPLIT PATTERN AT JOINT LINE

i.e. in three moulding boxes instead of two. All similar column or pedestal castings made in metal-pattern form would need to be similarly moulded. Advantages of this system are the saving of core-making time, drying and oven space, the elimination of core misplacement and its inherent crushing of the mould (resulting in porous and badly shaped castings) and, not the least important, the permanent nature of a smooth-working pattern not giving moulding trouble by splits and crevices created in rapping.

Bosses on Split Columns or Pedestals

The reader who appreciates the wide possibilities of the method above described will now be wondering what happens if the job in hand has numerous bosses which would not "draw" or remove from the mould by "loose" pieces. Cores? Yes. Coreprints, making the pattern very heavy again? No. Take a careful look at Fig. 56. An actual sand core is being tried in place on the inside of the metal-column pattern. Note that the core is made to fit over a rib which is adjacent to the position of the boss impression *in the core*; also the local shape of the wall upon which the core is about to be laid is recessed in the core itself.

How the Loose Cores are "Moulded-in"

This may well be described as a "loose core—*without coreprints* moulded in its place." A description such as the above is self-explanatory, but the

FIG. 56.—TESTING THE FIT OF A LOOSE "MOULDED-IN" CORE

keen reader will want to know just how it works. The core having been made from a corebox that is shaped as part of that particular section of the pattern will obviously fit snugly on to the pattern—see Fig. 57.

In the foundry the moulder takes his loose cores and places them in position, packing a suitable amount of sand around each one to hold the core firmly whilst the main mould ramming is completed. When the pattern is actually drawn from the mould, all the "loose-cores" are left behind—*ready placed and locked in position* without further work. Therefore it will be seen that heavy coreprints on patterns of the type now being dealt with are not only unnecessary, but a complete disadvantage, as by the foregoing description we find a saving in time taken by the moulder in "coreing-up" his mould—this being entirely eliminated, together with any possibility of rubbed or misplaced cores and badly matched coreprints.

Coreboxes for Metal Patterns

Although coreboxes get the same hard (and often harder) wear as their patterns, it is generally possible to so construct a corebox in hardwood that it lasts for an enormous number of castings. Wear naturally takes place mostly on the joint or ramming faces, and reinforcing by means of $\frac{1}{8}$-in. thick brass plates is the most common method adopted for prolonging the life of wood

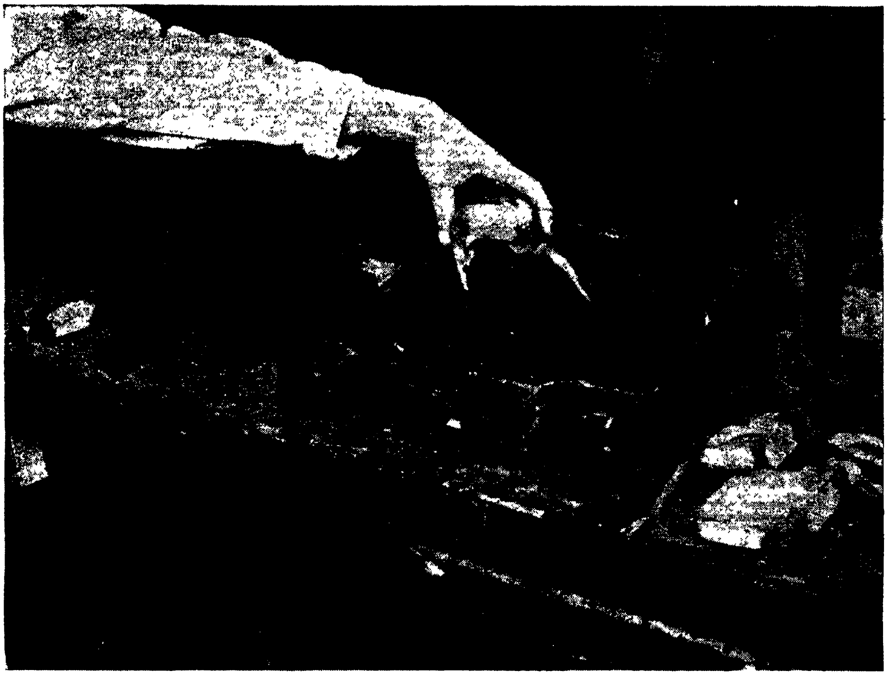


FIG. 57.—SHOWING HOW THE CORE RESTS IN POSITION "WITHOUT" COREPRINT ON THE PATTERN

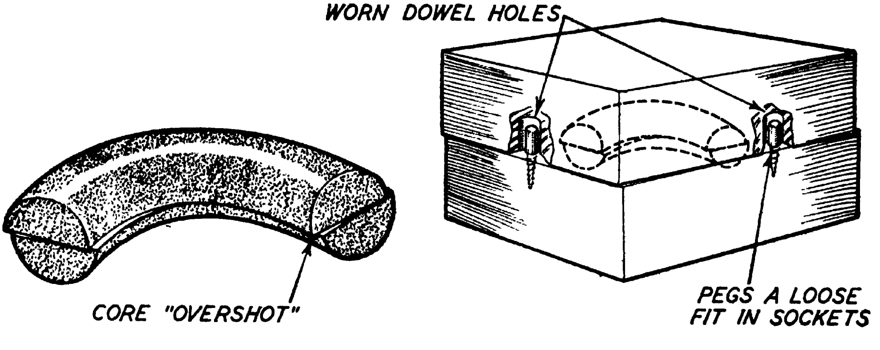


FIG. 57A.—A PIPE COREBOX AND ITS CORE AFTER RAPPING, THE COREBOX HAVING "SLOPPY" FITTING DOWELS, RESULTING IN A "STEPPED" OR "OVERSHOT" CORED HOLE

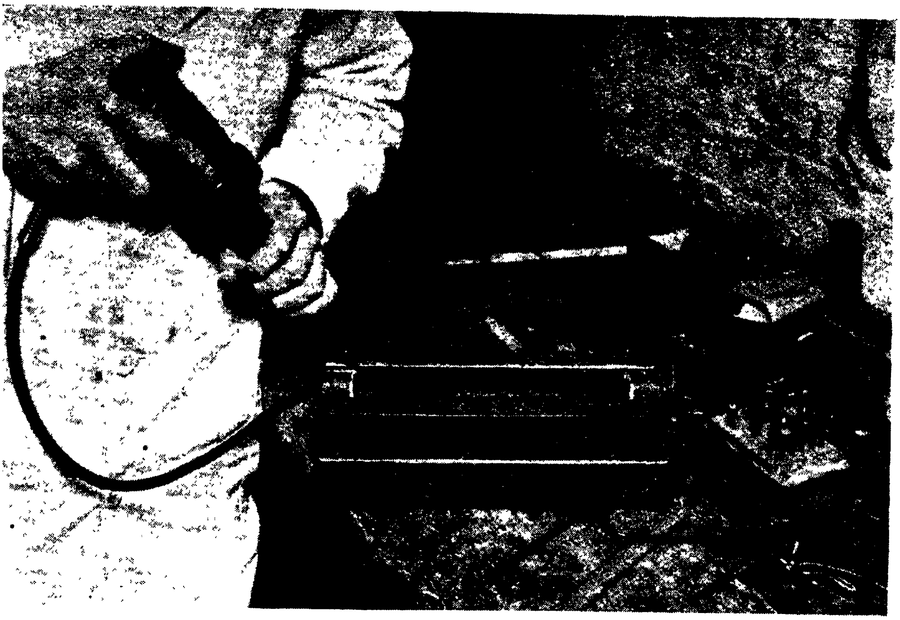


FIG. 58.—DRESSING SMALL RADII WITH THE HIGH-SPEED HAND GRINDER

coreboxes in that respect. A frequent coat of shellac polish between a "run" of castings is also very effective in stimulating good cores and prolonged corebox life.

Metal Coreboxes

Cast iron is largely favoured for production coreboxes which, when used on a core-blowing machine, withstand the abrasive effect of the sand better than the non-ferrous metals.

Lightness in handling being of great importance in most pattern equipment —of which coreboxes naturally form a part—the pattern-maker should generally remove all surplus material when making the master-wood for a cast-iron corebox, and excepting the special circumstances which do arise such as for securing dowels, etc., the wall thicknesses should be between ¼ in. and ⅜ in., certainly not much heavier.

Aluminium coreboxes, of course, may be of greater wall thicknesses than cast iron, and in regard to popularity in the foundry, the favour is not on this metal for reasons as stated in the pattern sections.

"Transplanting" for Complete Plates

Assuming we have a simple switchbox to make, and that the size of the proposed switchbox is small enough to enable four metal patterns to be mounted

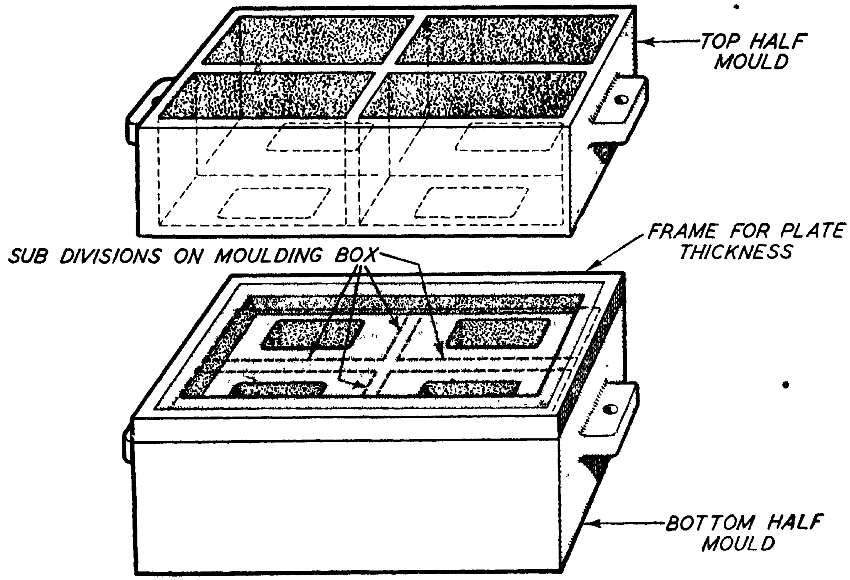


FIG. 59.—PLATE PATTERN

on a plate—all that is necessary for the master-wood pattern is just *one* complete "shell" made with relief on the underside precisely as the final castings will appear.

The foundry now take a hand in the matter, and by choosing a moulding box of suitable size to accommodate four impressions of the master pattern, follow this procedure. Both halves of the moulding box are subdivided into four "pockets" by temporarily fixing a cross of two wood struts into each. The master pattern is now moulded four times (one in each pocket) and a frame equal to the thickness of the moulding plate, say $\frac{1}{2}$ in., is laid upon the top edges of the bottom-half moulding box; the actual plate or a wood pattern is now moulded on top of the four switchbox moulds, and the upper-half mould lowered into its position for casting on to the edge of our $\frac{1}{2}$-in. frame. This frame is left in its original position, serving the purpose of a shallow middle box, and the pattern plate is, of course, withdrawn from the shallow frame before closing the top moulding box on to the bottom moulds. Having cast the mould now described, we obtain a double-sided plate of four patterns.

Clean-up Only

Naturally, plate patterns made in this manner would only permit the metal pattern-maker lightly to file and scrape the whole all over, but if the complete process is painstakingly carried out, some exceedingly good results are quickly obtained at a comparatively low cost (Fig. 59).

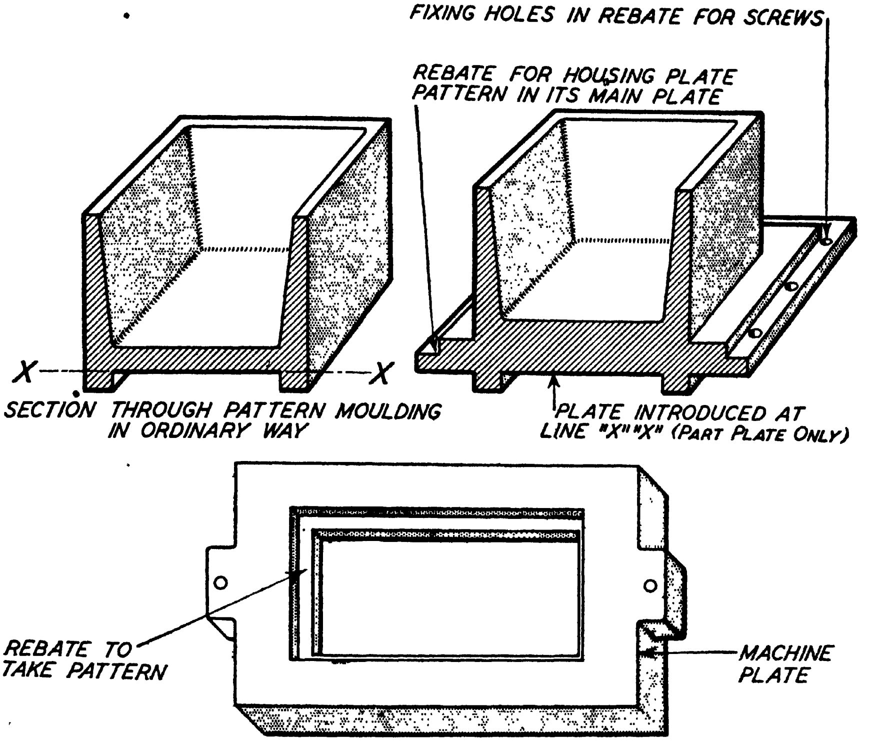


FIG. 60.—RAISING MOULD FOR "LET-IN" PATTERNS

Raising Mould for "Let-in" Patterns

A metal pattern may be required for a large casting that will only permit of one per plate. At the same time, it may happen that the main dimensions are not important so far as contraction is concerned, and in this way an existing wood pattern can be brought into service as the master pattern.

The procedure is identical with that previously described for complete plates, except for the four moulds and their preparation. A flange is formed by a flat piece of $\frac{1}{2}$-in. wood or metal of suitable size, which in due course has a rebate machined in to enable fixing at plate-level (Fig. 60).

Equipment and Use

Grinding forms a large proportion of work when making metal patterns, although the file is generally used for the actual finishing.

Light portable hand grinders of very high speed are extremely useful tools, enabling the most difficult of shapes to be cleaned out ready for riffler, buff, and emery. Fig. 58 shows a tool of this kind in use, and also shows an assortment of shaped "points" which are used to get at various peculiar corners, hollows,

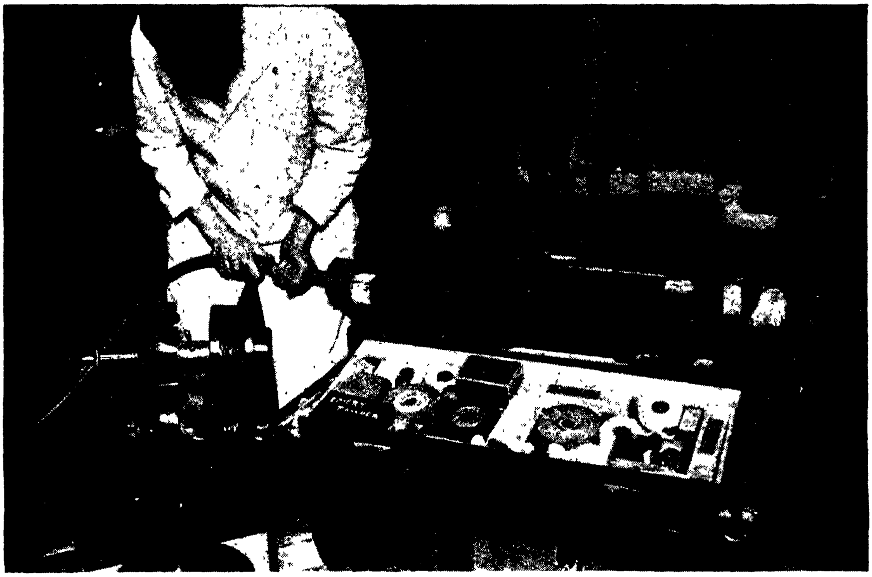


FIG. 61.—THE LARGE FRAME PATTERN WITH TIE-BARS REMOVED (ACTION IN FIG. 52) AND LINED OUT (FIG. 51) HAVING PRIMARY DRESSING WITH PORTABLE EQUIPMENT

slots, etc., the common lot of the metal pattern-maker. It must be noted that these tools are only suitable for *light-duty* work, and overloading is only liable to cause breakdown and loss of time, thus offsetting any time gained, by the spoiling of the tool for its real job.

Heavy-duty Tools

By way of contrast and to show how large iron patterns are prepared, Fig. 61 gives an idea of the kind of equipment suitable for really hard work. A hollow-cup stone is being employed to flatten off the side of a pillar that has developed a bulge on the raw pattern casting. Uneven lumps have a nasty habit of occurring on pattern castings, and, of course, these must be removed as part of the "truing-up" process.

Filling up Sinkages

No doubt the reader will be familiar with soldering and sweating methods as applied to ordinary engineering jobs, and metal patterns do not differ in their treatment, except that cold soldering is not a good job when filling up a drawn or sunken section of any size, having a tendency to curl out after some wear on the pattern. Best results are obtained by heating *the work* to run the solder, and Fig. 62 shows the gas blowpipe in action, where it will be noted the flame is directed on to the *metal pattern* which, when hot enough, will by contact

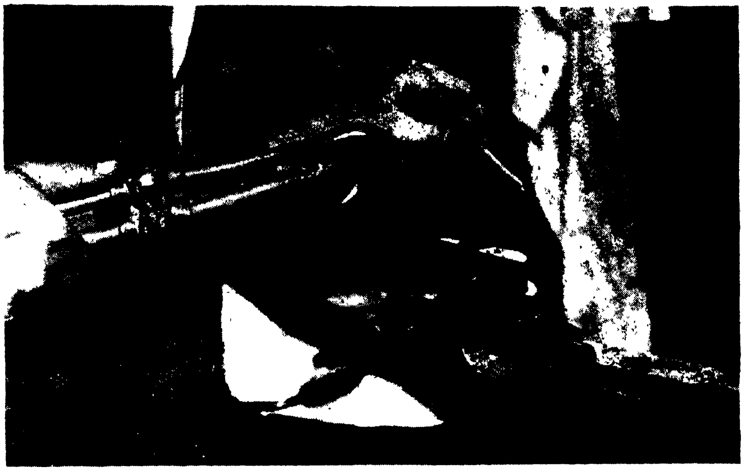


FIG. 62.—SWEATING AND FILLING UP THE SCREWHEADS TO A HALF-COREPRINT ADDED AFTER MACHINING THE METAL PATTERN. GAS BLOWPIPE IN USE

with the solder melt the latter and make a good lasting joint without the use of any soldering bit—just dip solder in flux and apply to the heated pattern.

High-production Metal Plate Patterns

Up to now we have considered the majority of our patterns for the foundry employing skilled or "loose-pattern" moulders. The making of plate-mounted pattern equipment to keep abreast of modern trends in the foundry industry, and worked by less skilled people than the loose-pattern moulders, calls for much additional knowledge on the part of the pattern-maker, particularly in regard to foundry technique, moulding machines, the use of metal-working tools (including machinery), and a wide angle on pattern-making as a whole.

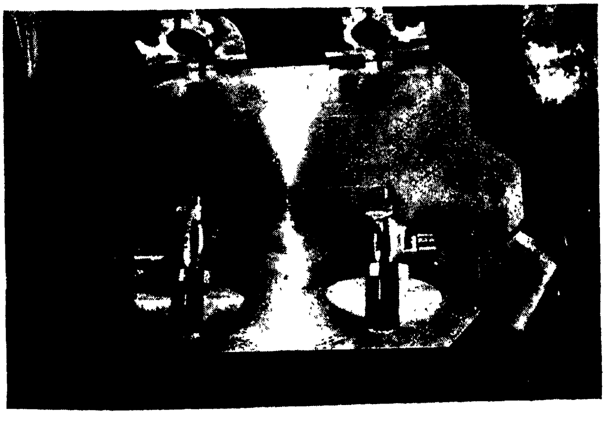


FIG. 63.—A SINGLE-SIDED PLATE FOR BOTH COPE AND DRAG

Showing two half-patterns fixed to plate, and the two halves which are matched being located by the dowels.

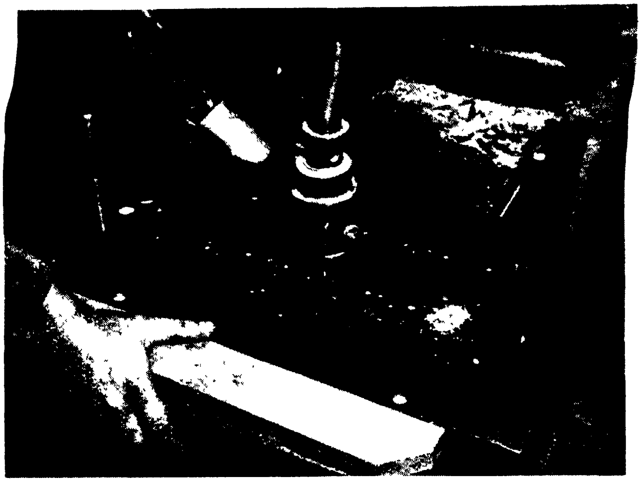


FIG. 64.—USING A DRILLING TEMPLATE WHICH IS LOCATED OFF THE COMMON PIN-CENTRES OF PLATE AND MOULDING-BOX, TO OBTAIN DOWEL POSITIONS FOR THE SINGLE - SIDED PATTERN PLATE

"Cope and Drag" or "Matchplate"

The bottom half of a mould being known as the "drag" and the top half as the "cope," the pattern-maker will be called upon to make equipment to produce either *one half*, e.g. drag or cope mould, and at other times to combine *both* drag and cope on one plate. The latter would be known as a "Matchplate," and the former, having one half pattern on one side only, would be known as the cope or drag pattern-plate, depending on the section of pattern (and runner system) incorporated on the plate.

Differences in Pattern Plates

Simplifying the last remarks to terms of patterns we may make:

(*a*) One single plate from which *both top and bottom* half-moulds are producible off the one working side only. This may be called a *single-sided plate for both cope and drag* (Fig. 63).

FIG. 65.—TURNED PATTERNS BEING POSITIONED BY A SINGLE CENTRAL PEG WHICH IS BURRED OVER ON THE UNDERSIDE TO FORM A RIVET FIXING

(*b*) Two single-sided plates which are essentially a pair, one plate having the half patterns for the bottom half mould (drag) and the other plate having the half patterns for the top half mould (cope). These would be called "*drag plate*" and "*cope plate*" respectively.

(*c*) One single plate which has a part of the pattern on *each* side, meaning that both sides of the plate are to be used to produce a complete mould. This is called a "*matchplate.*"

Excepting the "matchplates," which are mainly self-determining, all pattern plates depend for their success on *careful location of the patterns in relation to the moulding-box pin centres.* Mostly these pin centres are only two in number on the average sizes of moulding boxes, which of course may vary according to the size and type of work proceeding in the foundry.

Reference to Fig. 64 will show that a piece of sheet-metal drilled accurately to match the two pins seen projecting at each end of the plate is placed on top of the pattern plate, and held in position by the long pins. Note that the sheet metal or drilling template as it now becomes only completely covers *one half* of the face of the plate, and it is on *this half only* that marking position of patterns is necessary, and the pattern dowel holes are first drilled.

Having obtained the dowel locations of one side of the centre line in the manner described, it will be obvious that by lifting the drilling template off the two locating pins and merely turning it over to cover the opposite half of the *same face* of the plate, a replica set of holes exactly the same distance from the pins can now be drilled through the holes first made in the drilling of template and one half of the pattern plate. This system has been found to be unfailing in accuracy provided reasonably good drilling is performed.

Fig. 65 shows the aforementioned system applied to ten half patterns each for a plate mounting the total of twenty top and bottom half patterns, one central dowel or peg only being employed in this instance.

Pressure-cast Aluminium Patterns

Gypsum plaster having an asbestos content is used as the moulding medium in place of sand for casting aluminium patterns and plates under pressure, thus producing a very good primary finish and reducing the cleaning-up time involved.

A master pattern is required in the first instance (wood or any other type will do), and a mould of the special casting plaster prepared in much the same way as a sand mould.

After drying, a metal cylinder lined with casting plaster is firmly secured to the runner opening *outside* the mould (through which the metal is to be injected), and a sheet of thin asbestos is placed as a baffle between cylinder and mould. An airtight pressure head is ready for clamping on top of this cylinder, and after the aluminium has been poured into the cylinder at a temperature near to the solidification point of the metal, the pressure head is closed, and compressed air, at about 5 lb. to the cubic inch, turned on, the sluggish metal being forced through the asbestos baffle into the plaster mould.

A very good system indeed, but not as economical as it might be, owing to the importation costs of the gypsum which, having an asbestos content, is not mined in Great Britain?

Much more could be written concerning the various moulding systems applying to the use and manufacture of pattern plates. As space does not permit this, a mention must be made of such machines as the Automatic reproducing die-sinking machine, the Pantographic engraving machine, the numerous Universal milling machines, and last, but not least, the humble lathe. All these are employable to good account on the production of fine-pattern equipment, and in various spheres are used to a great extent.

Finally, it should be remembered that the *finish* of a metal pattern depends as in most other practical work, on the skill of the individual craftsman, and no little emphasis is laid on the use of the file, hand-grinding machine, scraper, buff, and emery cloth, not to mention the numerous little gadgets like rubbing sticks with a pad of felt and carborundum powder, a chasing tool or two of home-made design, and the various little items a craftsman finds useful in the course of his battles with the "awkward jobs." None should be despised, and all should be applied only with discretion and in the right place to perform the best job in the quickest time.

Plastic Patterns

Successful reproduction of duplicate patterns for quantity casting has been achieved off a plastic material which is actually far better than wood as a moulding medium, and indeed *equal to metal* in many instances. Up to this moment experiments have been confined to small patterns, but undoubtedly there is a great future for plastic patterns as a whole for *economic* and practical reasons.

On patterns coming within a 6-in. cube as overall dimensions, there is *no need to make a special or extra shrinkage allowance* on the master pattern, as the factor involved is only 1 in 200.

Heat treatment is given to the plastic in the course of manufacture, and after that process *the material is dimensionally stable* under most severe working conditions.

B. L.

MODERN FOUNDRY PRACTICE

THE general procedure for producing a casting is the same for all materials, and consists of pouring molten metal into an impression made in sand from a suitably shaped wood or metal pattern. However, in spite of this similarity there are certain important technical differences for each metal, and it is impossible to obtain good results unless these are observed. This applies particularly to steel, the melting temperature of which is considerably higher than that of other metals, and in the following survey attention is drawn to these differences in technique. Because the subject of foundry mechanisation and layout is dealt with thoroughly in the following section very little reference is made to it here.

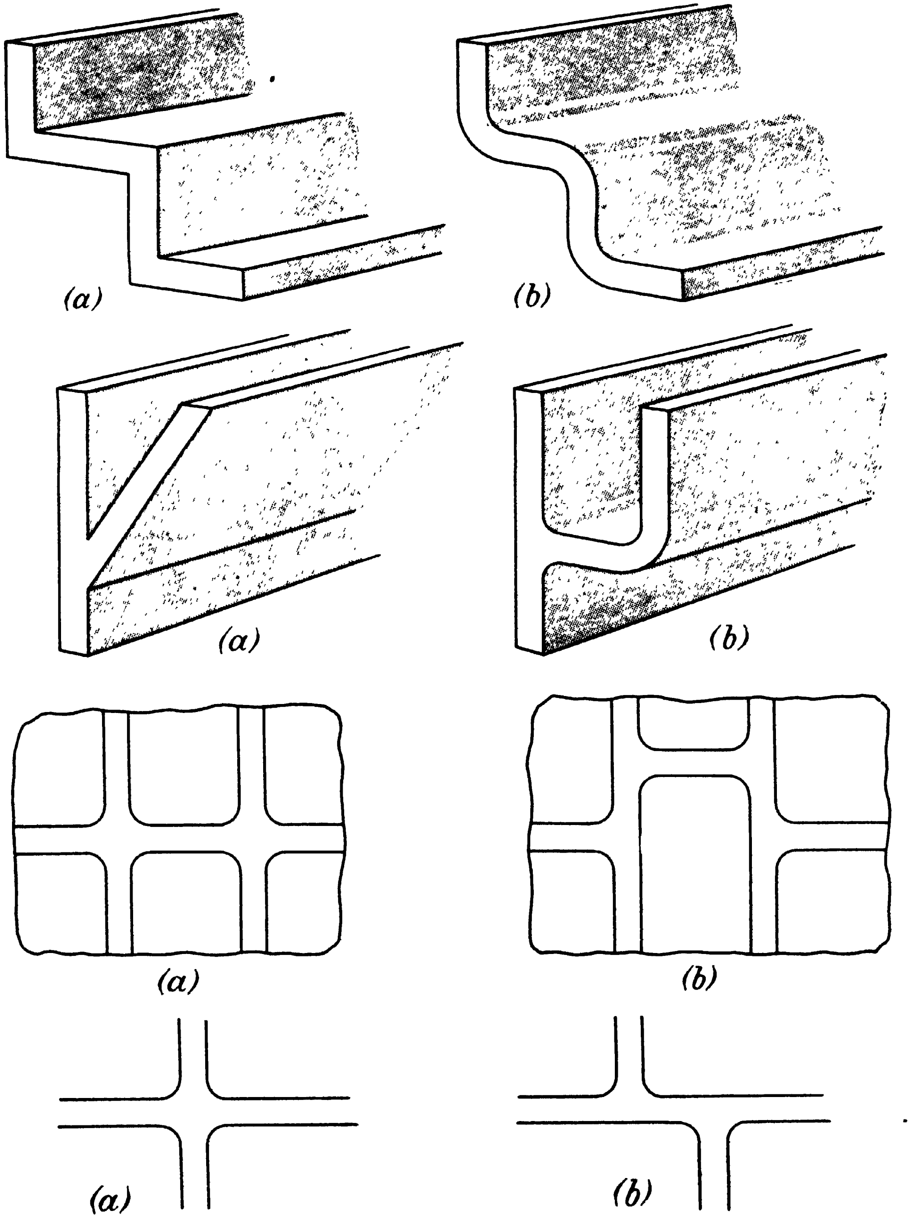
CASTING DESIGN

To obtain the best results, it is essential to remember, during the preliminary design stages, that the part is to be produced as a casting. Also, if possible, the design should be discussed with the founder, as the latter's experience often makes possible simple modifications which may cheapen production costs and enable quicker delivery without affecting the function of the casting. Unless the designer is really expert in foundry matters, it is quite possible for him to design a component which cannot be produced successfully as a casting or, alternatively, which will be difficult and expensive to make.

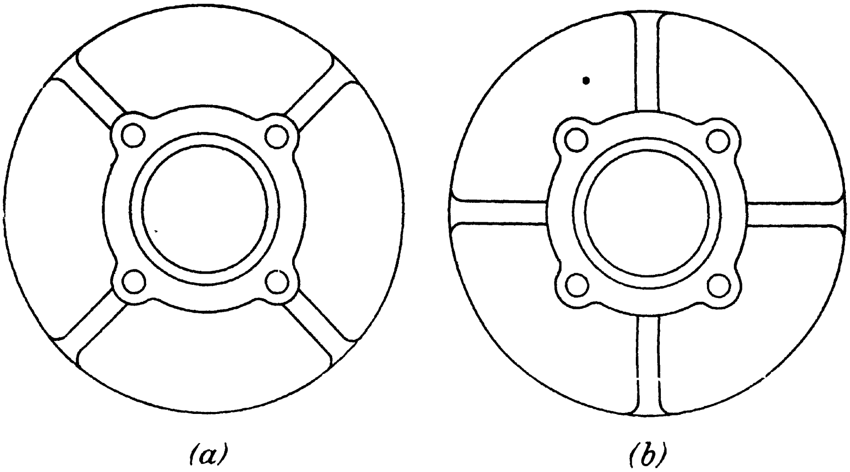
Shrinkage Effects

All metals shrink as they solidify, an elementary fact which can have an important effect on the design of castings. The rate of contraction varies from metal to metal, and the calculation of this is not always a simple matter, as may be seen in the case of steel, for which there are three stages. First, there is the actual contraction of the liquid in the ladle, this being followed by a further contraction of approximately 3 per cent. of the total volume as the metal changes from the liquid to solid state in the mould. Finally, whilst cooling in the solid condition, there is a further contraction amounting to approximately 7½ per cent. of the volume, allowance being made for this latter contraction when making the pattern. This third stage of shrinkage can be accurately calculated, and thus does not introduce any difficulties.

However, from a design viewpoint, care must be taken of the second phase of contraction, during which the casting shrinks approximately 3 per cent., for



FIGS. 1 AND 2.—UNDESIRABLE DESIGN FEATURES (*a*), AND (*b*) SUGGESTED METHODS FOR AVOIDING THEM



FIGS. 3 AND 4.—FROM A CASTING VIEWPOINT (*a*) IS OF BAD DESIGN, BECAUSE THE RIBS TEND TO DRAW THE METAL FROM THE BOSSES AND LEAVE THEM UNSOUND

unless means are provided for supplying this extra liquid steel, the casting is likely to contain cavities or the surface be deformed. To overcome this difficulty, the feeding systems must be so arranged that this extra metal is supplied to the parts where it is necessary. Here, consultation with the founder may make modifications possible to facilitate running methods, and so improve the quality of the finished product.

Another major consideration for the successful design of castings is concerned with the rather obvious fact that heavy masses of metal take longer to cool than lighter sections. Consequently, it is possible for one part of the casting to be solidifying whilst an adjacent part is still liquid or in a semi-plastic condition. Thus, the portion solidifying first will be contracting and exerting a pulling force on the adjacent plastic material which is not able to offer much resistance. This results in a defect known as a "hot tear," which can be sufficiently serious to result in complete scrapping of the casting. However, by suitable design and running considerations, this defect can be avoided. Sometimes the careful use of external and internal chills provides the solution to maintaining an even rate of cooling throughout the casting. In all cases, the ideal to be aimed at is to design the casting so that, as far as possible, all parts solidify at the same rate.

Design Considerations

In general, no section of a steel casting should be less than $\frac{1}{4}$–$\frac{3}{16}$ in. thick. As far as possible the joining of thin sections to thick sections should be avoided, but, where this is not feasible, the designer can assist the foundryman by adding metal to make the change of section more gradual, and thus eliminate

concentration of stresses. Where sharp corners occur at changes of section, a plane of weakness is formed along the length of the inside corner, and this may be avoided simply by providing a comfortable inside radius. Other ways to avoid bad design are illustrated in Figs. 1 and 2, whilst Fig. 3 shows another undesirable design feature which, if possible, should be modified in the manner shown in Fig. 4. Sometimes a rib or member joined at each end to heavier sections can be curved in such a manner that it tends to straighten during contraction, thus relieving the stresses at the ends. A typical example of this is provided by the curved spokes often seen on wheels.

SAND PRACTICE

The fact that rigid sand control is one of the essentials of the production of high-quality castings is appreciated by every firm of importance, and practically every modern foundry now has a laboratory staff engaged solely with checking the sand at regular intervals, which may be as short as half an hour, or even less. This applies particularly in the case of steel foundries.

Sands from different parts of the country vary considerably in composition and quality, some being more suitable for one particular application than for another. For example, certain types consist of smooth polished grains, which do not provide as good a holding surface for the moist clay bond as those with a rough surface. Some grains are rounded, others are sharp and angular, whilst others are composed of masses of smaller grains cemented together. Each type imparts special characteristics to the sand, either good or bad. In earlier days, each foundryman had his own favourite sand mixtures, which were evolved as the result of experience. Now, however, due largely to the effect of foundry mechanisation and an increased knowledge of sand properties, most foundries use only two or three mixtures for their entire range of work. In fact, where machine moulding is extensively employed, a single standardised "unit" sand usually suffices, providing that all the castings are of a generally similar type.

Sands for foundry use are composed almost completely of grains of a highly siliceous nature, together with very small amounts of other minerals and, sometimes, a percentage of undesirable impurities, such as magnesia, lime, potash, soda, and iron oxides. Certain sands also include some form of clay which acts as a bond to hold the grains together. Such types, known as *natural bonded sand* or *natural moulding sand*, are often suitable for foundry use without special treatment. Sands which do not include a natural bond are known as *sharp silica sands*, and require the addition of artificial binders or bonding clay before they can be used.

Properties

To be suitable for moulding, a sand must possess certain specific properties, the more important of which are given below. These may be divided into two groups, one concerned with the actual moulding properties of the sand, i.e. with producing clean, accurate contours, and the others with the functioning of the mould, i.e. the escape of gas, and so on.

PLASTICITY.—An essential requirement if a clean impression is to be obtained from the pattern is the control of the amount of moisture and clay bond present in the sand. If the clay content is too high, it fills the interstices of the sand, thereby reducing the permeability; on the other hand, excessive moisture results in the generation of steam when the molten metal is poured, this applying particularly to green sand. Another effect of excessive moisture content is that the sand packs together too tightly under the effect of ramming, thus reducing the permeability. With dry sand, excessive moisture is liable to result in the mould sagging out of shape when the pattern is removed.

BOND STRENGTH.—This term is used when referring to the ability of a sand mixture to hold together, and enables the pattern to be drawn without collapse of the mould. It is controlled chiefly by the clay content, with which the sand grains become thoroughly coated during mixing so that they adhere firmly together when rammed. The size and shape of the sand grains also affect the bond strength. For instance, an assortment of irregular shapes and sizes will result in a much tougher mixture than when the grains are all of uniform size. Under similar bonding conditions, angular grains give greater mechanical strength than round grains, and thus this shape is desirable in cases where maximum strength is required. On the other hand, rounder grains "flow" more easily and also give higher permeability; consequently, they ram easily, and thus this type of sand is particularly suitable for machine moulding purposes.

When the clay loses its moisture, it becomes hard and useless as a bonding agent. Up to a certain temperature, only the "free" moisture is removed by drying, and this may be replaced by the addition of water to restore the clay to its original condition for re-use, as is done during reprocessing in the ordinary sand reclamation plants. However, when heated considerably past this temperature the natural inherent moisture of the clay is driven out, leaving a hard, inert substance which cannot be reclaimed by the addition of water. This occurs to the sand in the mould face when it is in contact with the molten metal. Fortunately, only a comparatively shallow layer is affected, the bulk remaining unaltered. It will be appreciated that the percentage of burnt bond steadily increases with repeated use of the sand, and for this reason new facing material should be used each time when moulding for steel castings. Because of the lower temperatures, this is not so important for cast iron and other metals, for which "unit" sands are generally suitable for both facing and backing purposes.

FLOWABILITY.—This term is used to describe the ease with which movement is transmitted through sand, and affects the speed with which the sand can be rammed. The smoothness of the casting surface is governed largely by the *fineness* of the sand. However, caution is necessary regarding this factor, because the permeability of the mixture decreases as the grain size becomes smaller. When the core or mould surface is to be subsequently treated with a wash, grain size is not so important as an aid to smooth surface finish.

PERMEABILITY.—A most important factor in the second group is permeability; this refers to the ease with which air and gases can escape through the

sand to atmosphere. It is, in effect, a measure of porosity. With green sand it is particularly important because of the high moisture content, which results in the liberation of considerably more steam than from dry sand. In the event of low permeability, there is the tendency for the gases to blow off portions of the mould face in their attempt to escape. Sand with large rectangular grains do not pack so tightly together as those with small irregular grains and, consequently, have a high permeability. However, as mentioned earlier, large grains have an adverse effect on the quality of surface finish, and thus careful compromise is necessary. Permeability decreases with the increase of clay bonding and used sand, which tend to choke the interstices between the sand grains.

REFRACTORINESS.—This term is used in describing the ability of sand to withstand fusion or melting when in contact with molten metal, and is of paramount importance when using steel. Should fusion occur, the surface of the casting will be defective, and there will be the danger of sand inclusions which would render machining very difficult. As this factor is controlled by the melting-point of the sand, the mixture should contain the maximum amount of free silica, and such impurities as magnesia, lime, potash and soda, which lower the melting-point, should be absent. The refractoriness of green sand may be increased by dusting the mould face with charcoal, blacking, or plumbago, whilst for dry sand moulds these two materials may be applied in the form of a wash.

Sand Definitions

A variety of different terms referring to sand are in common foundry use, the more important of which are given below:

SYNTHETIC SANDS.—These are prepared artificially from unbonded sharp silica sand by the addition of artificial bonds, this term also referring to sands bonded with organic materials, oil, or cements.

The expression *green sand* denotes that the sand is in an undried condition. The process eliminates the expense and delay of drying the moulds, and enables a higher output from the available floor space. Green-sand moulding is widely used for cast-iron work, and also for small and medium-size steel castings, but should not be used for large work because of the quantity of steam which is liberated. In general, green-sand moulds are not as strong as those made from dried sand.

DRY SAND.—This is sand from which the "free moisture" has been removed in an oven. Because the moulds are harder and will withstand more handling than green-sand moulds, they are used almost exclusively for large work. In general, castings made by this process are much cleaner and of better quality than those made from green-sand moulds, this being due to the absence of steam. Again, because of the absence of steam, the amount of venting and sprigging necessary is considerably reduced. On the other hand, the dry-sand technique necessitates the installation of drying ovens, requires a larger number of moulding boxes, and a certain amount of delay occurs because of the time occupied by drying.

From earlier remarks it will be seen that the bond of the sand adjacent to the impression is destroyed by the heat of the molten metal. Consequently, repeated reclamation of the moulding sand results in deterioration of the bond quality, even if new sand is added during the process. This has the effect of lowering the refractoriness of the sand, with the result that surface defects are likely to be caused by the fusion of the sand and metal. This trouble does not arise very often with iron because of the lower temperatures, but with steel castings it is a factor of considerable importance. Consequently, in order to obtain optimum results, it is the usual practice to surround the pattern for steel work with a layer of new sand containing the correct proportion of bond. This is known as *facing sand.*

BACKING SAND.—The sand used to fill the bulk of the box is known as *backing sand.* This does not come into direct contact with the molten metal, and comprises sand from previous moulding operations, and has a lower refractoriness and bond strength than new sand. In the case of smaller foundries not equipped with reclamation plant, the backing sand is usually left in the same condition as when knocked out of the mould. However, in modern mechanised foundries, the used sand is circulated through a reclamation system, where new bonding material, new sand, and water, is added, making a "unit" sand which is practically as good as the original facing sand. Provided that it will sustain the liquid pressure, practically any material could be used as backing sand.

SANDS FOR CORE MAKING, ETC.—As the name implies, core sand is used for core-making purposes, and usually comprises a synthetic sand mixed with special core binders. Generally, it contains grains with a very high silica content, although it is also fairly common practice to use ordinary moulding sand for this purpose. *Oil sand* refers to sands bonded with an organic binder, and is usually employed for core making. Materials such as linseed oil, dextrine or other drying oils are used for binding or bonding purposes.

The single, standard mixture provided by a mechanised sand preparation or reclamation system is generally known as a *unit sand* or a *standard sand.*

SHEFFIELD COMPOSITION.—Special problems arise when making very large steel castings, due chiefly to the difficulty in finding a mould material capable of fulfilling its various functions when holding anything up to two or three hundred tons of molten metal, and which may take several weeks to cool. The most satisfactory results are provided by a mixture known as Sheffield composition or *compo*, which is now used almost exclusively for mould-making purposes in heavy steel foundries. Originally it was made by crushing old crucibles, fire bricks, ganisters and fire-clay, to which was often added graphite or coke to increase the refractoriness; but in recent years a number of proprietary mixtures have been marketed. Compo has exceptionally good refractory properties, retains its strength at high temperatures, and is very permeable.

RANDUPSON PROCESS.—A few firms in this country use a moulding material comprising a mixture of sand and Portland cement. Known as the Randupson process, it was originally developed in a French steel foundry. The mixture

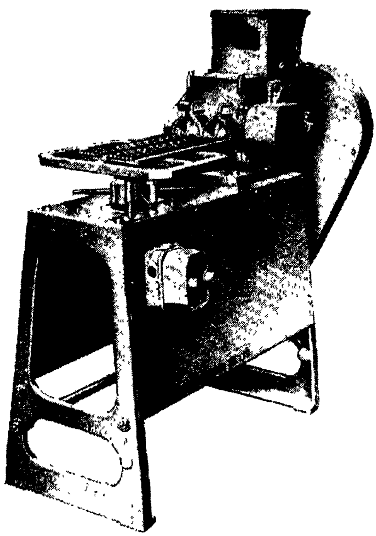


FIG. 5.—A MULTIPLE-CORE EXTRUDER FOR MASS-PRODUCTION WORK
(*The Fordath Engineering Co., Ltd.*)

consists of clean silica sand mixed with approximately 10 per cent. cement and a suitable amount of water. The moulds are air dried for approximately three days, after which they are used in the normal manner. The process is claimed to possess certain advantages for heavy castings, due chiefly to the higher strength of the cement mixture. The cost of drying stoves is eliminated, but a considerable amount of storage space is necessary because of the extended air-drying period.

Iron Practice

In many iron foundries, naturally bonded sands, sometimes with small additions of a bonding clay, are employed for moulding. Often, the sands are finer than those for steel work, this meaning that the permeability is lower. For general work, green-sand moulding is employed, dry-sand practice being reserved mainly for high-quality castings such as are required by the engineering industry. Except in the case of mechanised foundries using a unit sand, the moulds are generally faced with a sand to which 3–10 per cent. of coal dust has been added. This addition has several effects, the most important being that the deposited carbon acts as a refractory coating of the sand grains and reduces chances of surface fusion, thus producing a smooth, clean skin on the casting. Also, it has been found that the oils from the coal dust tend to increase the dry strength of the sand.

When moulding heavy iron castings, use is often made of *loam*, this being a strong sand mixture containing an addition of fire clay or ganister, which is applied to the surface of the mould or core in the form of a facing material.

Core Materials

The requirements for core materials are practically identical to those for moulds. However, special emphasis must be laid on the fact that the core must be sufficiently weak to allow the metal to contract normally as it solidifies, as failure of the material to collapse under contraction pressure is a very common cause of such defects as "hot tears" and "locked-up stresses." Dry-sand cores consist of a sand mixture held together with a gum, binder or bonding material which hardens after treatment. A wide variety of binders are in common use, each possessing special properties which render them suitable for some particular application.

CORE PRODUCTION

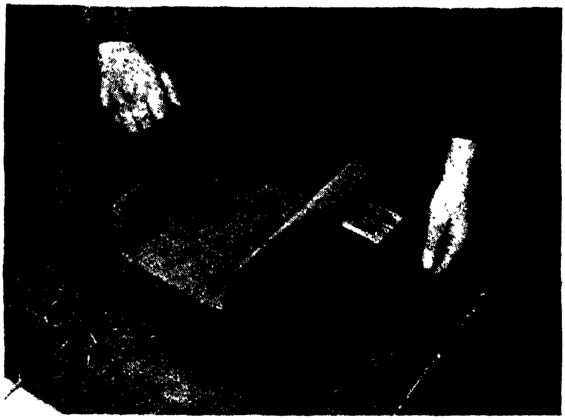


FIG. 6.—FINAL HAND-TRIMMING STAGES DURING THE MAKING OF A CORE

Because of the fact that cores are often nearly completely surrounded by molten metal, considerable volumes of gas are produced, and it is essential for these to be able to escape quickly and without passing through the metal. For this reason the provision of adequate vents or passages is important, these leading to some position from where they can be led off to the atmosphere.

Compared with moulds, cores are comparatively weak, and thus it is often necessary to strengthen them with core wires, i.e. small pieces of wire bent to a suitable shape, whilst for large work additional strength is provided by reinforcing with internal cast-iron grids. To prevent breakage or deformation, especially in the green state, cores should always be transported on sturdy flat plates: for intricate shapes these are often made specially to suit the contours.

Machines

Cores are produced either by hand or on machines, the choice being governed by such factors as quantities required, shape, and size. For machine work, many of the types of equipment employed for moulding purposes are quite suitable. Small and medium-size simple cylindrical cores required in large quantities are often made on an extruding machine (Fig. 5).

The thrust is imparted to the sand by an impeller-blade revolving in the horizontal plane; this is an advance in design of the conventional worm-conveyor, and enables a larger thrust surface to impel the sand through the extrusion barrel of two dies simultaneously.

To ensure even feeding of the sand to the die-face, a secondary impeller, operated by a chain drive, is installed in the rear of the feed chamber. This enables the large-volume hopper to be filled with sand, which is automatically fed to the front impeller and forced through the dies.

When quantities of more complicated shapes are required, the core-blowing machine is very useful: with this the sand is blown at high pressure into a metal core box. Very good results are obtained, because the sand packs firmly and uniformly into all the cavities of the pattern impression.

Much of the accuracy and quality of cores is controlled by the drying

FIG. 7.—A HAND-TYPE CONVEYOR IN A MODERN CORE SHOP, WITH THE BENCHES ARRANGED ON EITHER SIDE

process, during which all the moisture must be completely removed. If the temperature is too high when the core is first placed in the stove, distortion and cracking is likely to result, whilst excessive temperature during drying may result in damage to the bond, thus causing the core to crumble. There are two main types of core-drying equipment, i.e. batch and continuous ovens, the choice of which is governed chiefly by the output of the foundry and the sizes and shapes of the cores. Where the quantities are not sufficient to warrant the expense of a continuous stove, or where the cores are very large, or in cases where the general run of work consists of widely different sizes and shapes, it is desirable to use batch-type stoves.

Checking

If the size or shape of a core is to be checked, this should be done after drying. In most cases a simple sheet-metal template cut to the main profile is sufficient. With mass-production work it is desirable to make a percentage check at regular intervals, even if gauging is not normally considered necessary. A simple and efficient method of checking is to keep a spare plaster-of-Paris mould and to fit every set of cores into it; for some work it may be possible to cut away portions of the moulds so that normally inaccessible parts of the cores can be seen or gauged.

When dealing with complicated core assemblies, which may consist of several cores grouped together, it is desirable to make a metal checking fixture

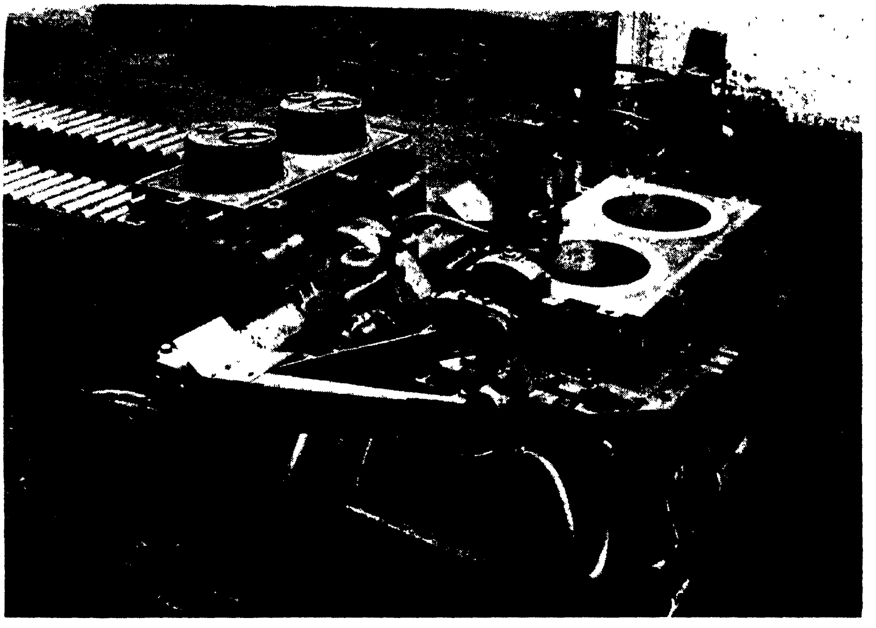


FIG. 8.—A TYPICAL MODERN MOULDING MACHINE. (*Pneulec, Ltd.*)

if sufficient quantities are required. The fixture should enable all the cores to be assembled in their relative positions and, if possible, allow easy access to all surfaces.

MOULDING TECHNIQUE

Moulds are made by hand or machine, the choice being influenced chiefly by the quantities required and the size (depth in particular) of the mould. The shape of the component also considerably affects the choice, as simple contours lend themselves to mounting on a plate for machine moulding. If all the conditions are favourable, machine moulding can be an economical proposition for quantities of twenty or more.

Hand Moulding

Hand moulding may be logically subdivided into two groups, i.e. that concerned with box or flask moulding, and the specialised branch dealing with very large and heavy work for which the moulds are made either directly in the foundry floor or in a pit. With the first type, the mould is made in a metal box or flask, the size of casting which can be produced being limited only by the size of the box available: there is practically no limit to the size of work possible when floor moulding.

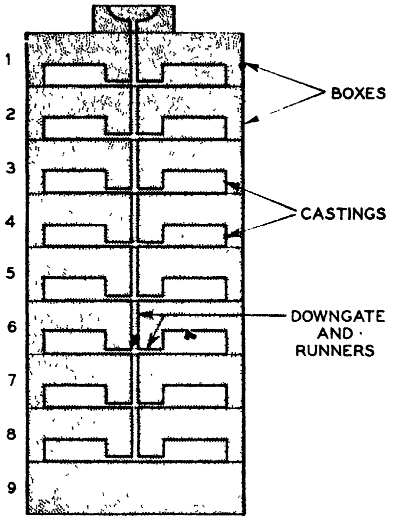


FIG. 9.—STACK MOULDING CAN SIMPLIFY PRODUCTION IF EMPLOYED FOR SUITABLE TYPES OF WORK

Floor Moulding

There are two main types of floor moulding, i.e. one using an "occasional pit," and the other employing a "permanent pit," the former comprising a hole excavated in part of the moulding bay, the hole being sufficiently large to provide 2 or 3 in. of clearance all around and underneath the pattern. For very large and heavy work, the permanent pit is employed. The actual design varies from foundry to foundry, and in some cases consists merely of a large brick pit with a solid, level floor. Alternatively, it may incorporate a cast-iron base and sides in the form of a large box, a substantial cover being secured on top by means of bolts.

Strickle Moulding

For certain classes of work whose contour is of a regular circular form, the mould may be produced without any need for an expensive pattern by shaping the interior with the aid of a "sweep" or "strickle board" rotated around a central vertical pillar. Thus, as the sweep is moved around its pillar, the wall of the mould is shaped to the same contours as those on the edge of the sweep.

Machine Moulding

Where large quantities of similar castings are required, machine moulding is far more economical and quicker than hand methods. The special advantages of the process include a high rate of production, lower labour costs, increased accuracy, and the fact that semi-skilled labour may be employed.

As a rule, only one half of the pattern is mounted on the plate; however, in some cases, particularly when moulding in iron, double-sided patterns are employed, enabling both halves of the mould to be made at one cycle by having a box of sand both above and below the plate. Within size and design limitations, most castings that can be produced by hand may also be produced on a machine, although large shallow castings provide an exception, as these can be rammed more satisfactorily by hand.

Types of Machines

The "pattern-draw" machine is the most simple example of equipment developed for machine moulding. It merely provides a means for withdrawing the pattern mechanically from the mould, ramming being done by hand.

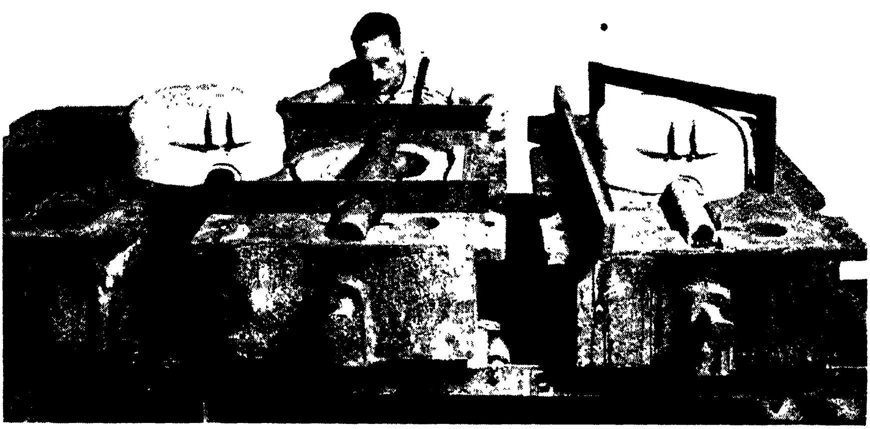


FIG. 10.—CHECKING THE SETTING OF CORES PRIOR TO CLOSING A LARGE MOULD

"Squeeze" machines incorporate means for mechanically pressing the sand into the box, thus eliminating the need for hand ramming. The ramming effect does not penetrate very deeply, and thus their use is usually confined to comparatively shallow work. On the other hand, they are very fast in operation, the complete cycle for squeezing and drawing occupying only a few seconds. With these machines it is often possible to use a double-sided pattern plate to produce drags and copes simultaneously. A variation of this machine is the "turn-over squeezer," which mechanically swings the finished mould clear from the table, turns it over, and withdraws the pattern.

Some squeeze machines are operated by compressed air, whilst for larger work hydraulically operated types have been introduced. In this case, instead of squeezing the sand down on to the pattern, the pattern is pushed up into the moulding box, with the result that the sand is hardest near the mould face, thus producing the ideal mould condition. It will be seen that with the other type of machine, the backing sand is rammed harder than the facing sand, which is undesirable.

In contrast to the squeeze-type machine, the "jolt" or "jar-ramming" type consolidates the sand by a jarring movement, the table rapidly rising and falling on to a solid base. The sand packs hardest on the pattern face, the effect progressively diminishing towards the top of the box. Being larger and heavier than the squeeze machine, it is employed for heavier work and deeper draws: the output is lower than from the squeeze and turn-over types. These machines are particularly suitable for general-purpose work.

A compromise between the squeeze and jar types is the "jar-squeeze" machine, which is suitable for smaller work than that usually made on plain jar machines. In particular, they are ideal for comparatively deep moulds

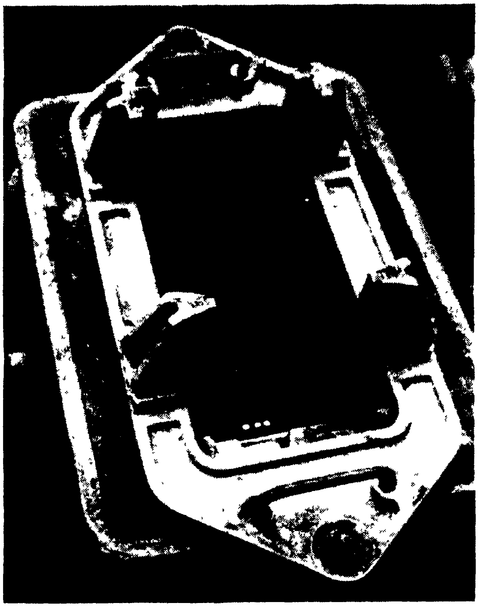


FIG. 11.—A SPECIAL FIXTURE DEVELOPED FOR CHECKING THE SETTING OF CORES WHEN CLOSING A CERTAIN MOULD PRODUCED UNDER MASS-PRODUCTION CONDITIONS

which cannot be rammed satisfactorily from the top. The operation consists of giving the machine a few jars to pack the sand closely around the pattern and sides of the box, then finishing off by squeezing from the top. It will be seen that this machine overcomes the weakness of the other two types regarding ramming.

For mass-production work, jar-ram machines are available which, in addition to ramming, also mechanically withdraw the pattern while the mould is still in the machine, an arrangement that considerably facilitates production. For medium-size and fairly large work, the "jar-ram turn-over pattern-draw" machine is very useful. With this, the finished mould is mechanically turned over and the pattern withdrawn in an upward

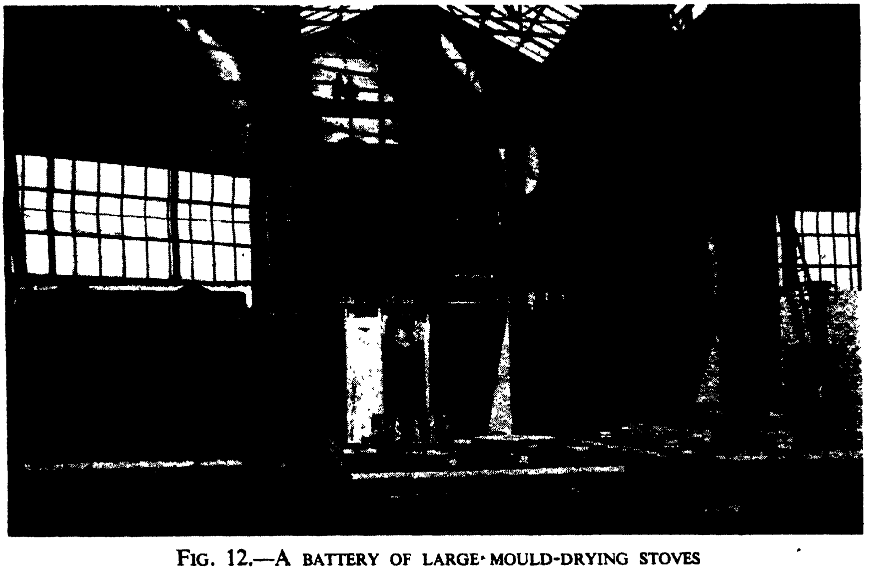


FIG. 12.—A BATTERY OF LARGE MOULD-DRYING STOVES

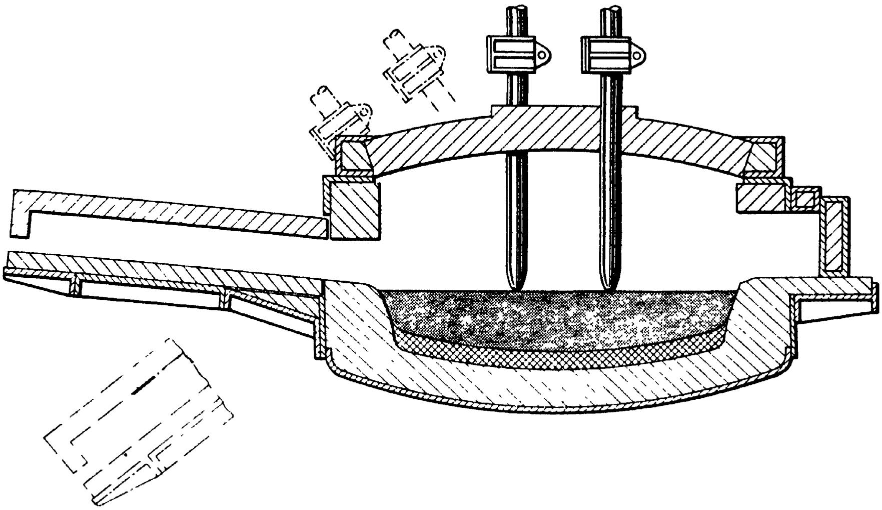


FIG. 13.—DIAGRAMMATIC VIEW OF AN ELECTRIC ARC FURNACE AS USED FOR STEEL MELTING

direction. This machine has the important advantage that it eliminates any need for a crane to lift the mould from the machine. Some large models are capable of handling up to 5 tons.

With larger moulds, considerable time may be saved by using a "sand slinger" for filling and ramming purposes. This equipment is designed to throw the sand with considerable force into the box, the flying sand packing tightly and evenly around the pattern. If facing sand is to be employed, the pattern is covered for a depth of an inch or two by hand and the sand pressed firmly around the contours, after which the box is filled with backing sand added by the slinger.

Centrifugal Casting

The centrifugal process is generally employed to produce circular, cylind-ical, and bell-shaped components, although many other shapes can also be cast without difficulty. It possesses certain advantages, the most important being that the metal in the circumferential edges and faces is exceptionally ound. The size of work is limited only by the size of plant which can be built, and the process is equally suitable for small quantities or large numbers. The amount of fettling required is considerably reduced, due to the fact that there is only a single header to remove.

Cylindrical-type sand moulds are used, feeding being down the centre, the unner also acting as the riser. Because of the spinning movement, the metal is lung outwards against the wall of the mould, thus producing an exceptionally mooth and sound outer face. In addition to single castings, the process may

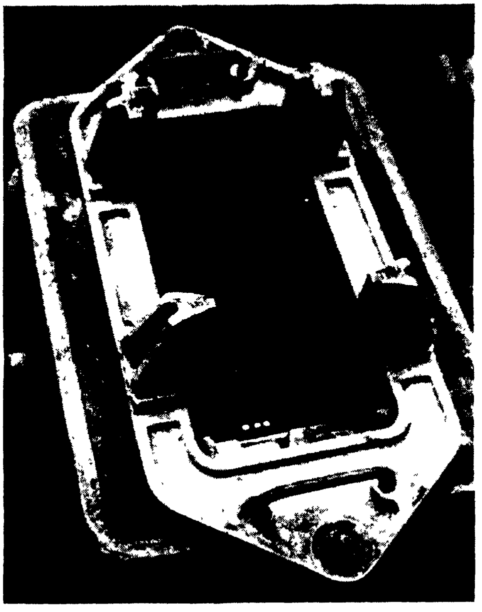


Fig. 11.—A special fixture developed for checking the setting of cores when closing a certain mould produced under mass-production conditions

which cannot be rammed satisfactorily from the top. The operation consists of giving the machine a few jars to pack the sand closely around the pattern and sides of the box, then finishing off by squeezing from the top. It will be seen that this machine overcomes the weakness of the other two types regarding ramming.

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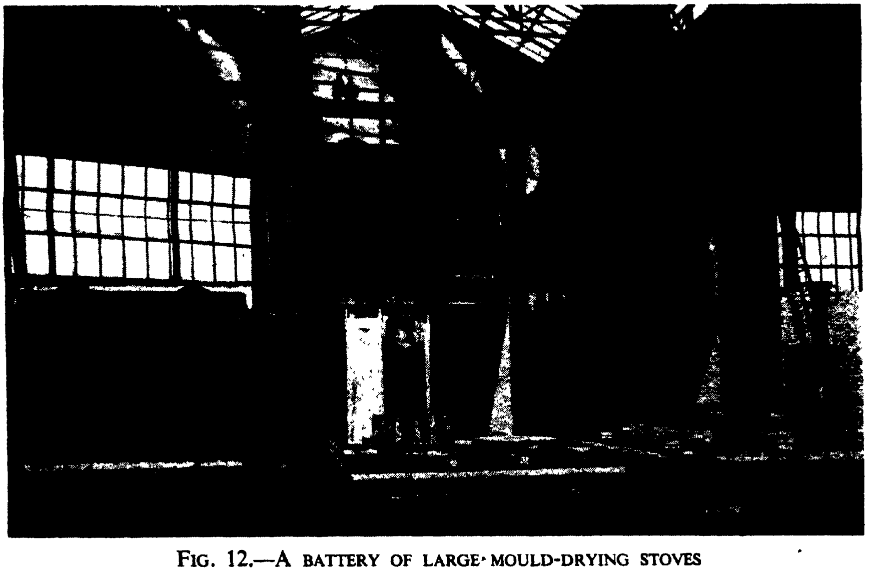
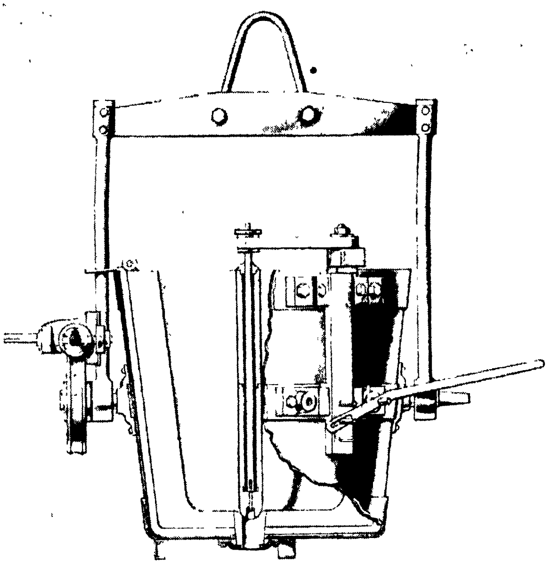


Fig. 12.—A battery of large mould-drying stoves

FIG. 15.—THE DESIGN OF THE BOTTOM-POURING LADLE

The impurities float on the top, and clean metal is run from the bottom when the stopper is raised by movement of the handle seen on the right.



importance because of the fact that incorrect gating may easily result in faulty castings, even if all other factors are correct. Where large quantities of similar castings are involved, it is a desirable policy to pass the first few components for thorough inspection—including X-ray examination—to determine whether changes in gating procedure are needed.

Many shrinkage defects due to unequal rates of cooling (i.e. solidification) can often be remedied by positioning the gates and heads to equalise, as far as possible, the rate of cooling in parts of different section thickness. Every casting has its own peculiar problems which can only be solved by practical foundry experience.

The type of runner system employed is influenced mainly by the need to eliminate two troubles. First, especially with deep moulds, the falling metal is liable to destroy or wash away that part of the mould surface on which it impinges, a fault which must be avoided at all costs. Secondly, it is essential to trap any loose sand, dross, or other foreign matter which may be present, and prevent it from remaining in the mould cavity.

Careful consideration should be given before using " top-gates," i.e. those through which the metal falls directly on the mould surface, and these should be avoided completely with the relatively fragile green-sand moulds. Their use should also be avoided if the metal is likely to fall for any considerable distance before striking the bottom of the mould. It may, however, be possible for the first metal poured to form a pool which acts as a cushion for the remainder of the falling metal. Top-gating is particularly suitable for long shallow castings, where the fall is not great and several gates are provided.

FIG. 16.—THIS VIEW OF A CASTING DIRECTLY AFTER REMOVAL FROM THE MOULD SHOWS THE EXTENT OF THE WORK INVOLVED WHEN FETTLING

Chances of damage to the mould surface can be avoided by using "bottom-running" methods whenever possible, the "down-gate" being so designed that the metal does not fall directly into the mould impression, but overflows into it via an "in-gate." A useful scheme is to provide the down-gate with a hooked dirt trap to retain the lighter impurities.

The "spinner-gate" provides a useful answer to the problem of preventing the entry of impurities into the mould, and is incorporated in the running bush. As the name implies, it is designed to impart a spinning or swirling motion to the incoming metal, this tending to keep any foreign matter in the centre of the bush, allowing only clean metal to pass from the bottom into the down-gate.

Risers or Feeder Heads

Risers or feeders have two main functions, one being that they prevent wastage of metal by indicating when the mould is full; the other is that they provide a reservoir of metal for compensating losses due to shrinkage during solidification. Unless an adequate reservoir of liquid metal is available outside the limits of the finished casting and able to supply additional metal, contraction will result in cavities and unsoundness.

Pouring

Accurate control of metal temperature and pouring speed are two important factors. If the metal is poured too slowly, solidification may commence before the mould is full; excessive temperature may damage the mould face and result

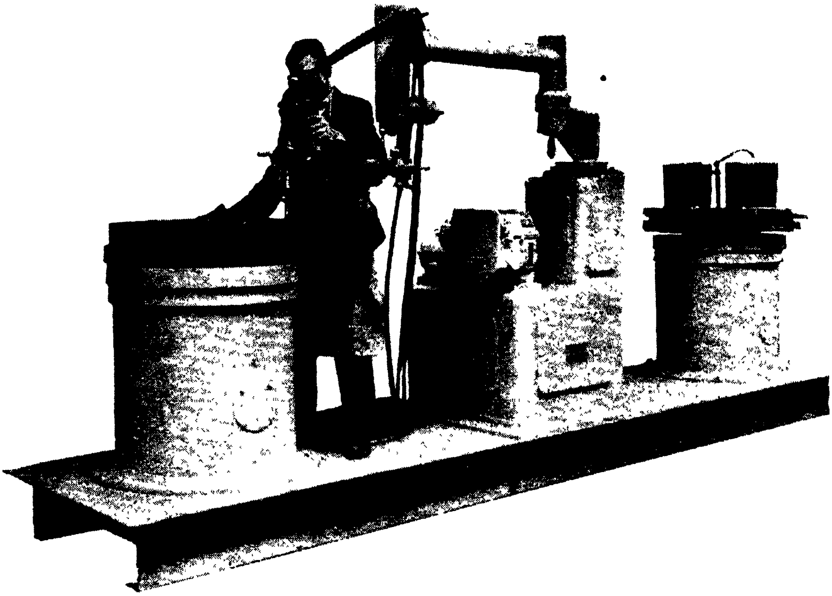


FIG. 17.—A TWIN-TABLE FLAME-CUTTING MACHINE FOR REMOVING RUNNERS AND HEADS FROM SMALLER STEEL CASTINGS

in faulty castings. During pouring, a steady stream of metal must be maintained, free from breaks likely to trap air. On the other hand, the stream must not be too violent, or damage will be caused to the walls of the mould.

NON-FERROUS FOUNDRY PRACTICE

Of the foundries engaged with non-ferrous work, those concerned with the production of aluminium castings are most common. The general foundry principles are similar to those for iron and steel, but particular attention has to be paid to certain stages, especially the melting, pouring, and feeding techniques. For instance, non-ferrous castings are generally designed with thinner sections than are possible with iron and steel, and this necessitates special attention to the gating or running systems. Also, non-ferrous alloys have a more penetrating effect than the ferrous metals, and thus care is necessary when ramming the moulds. These metals are particularly weak at high temperatures, and this means that every effort must be made to avoid restriction to contraction as the metals solidify, especially as the work usually incorporates very thin sections. Much closer observance of pouring temperatures is also important.

FETTLING

Fettling consists of removing the runners, risers and "flash" metal at the joints, and of trimming and cleaning the casting generally to the final contours and condition specified by the customer (Fig. 16). Although much of the sand

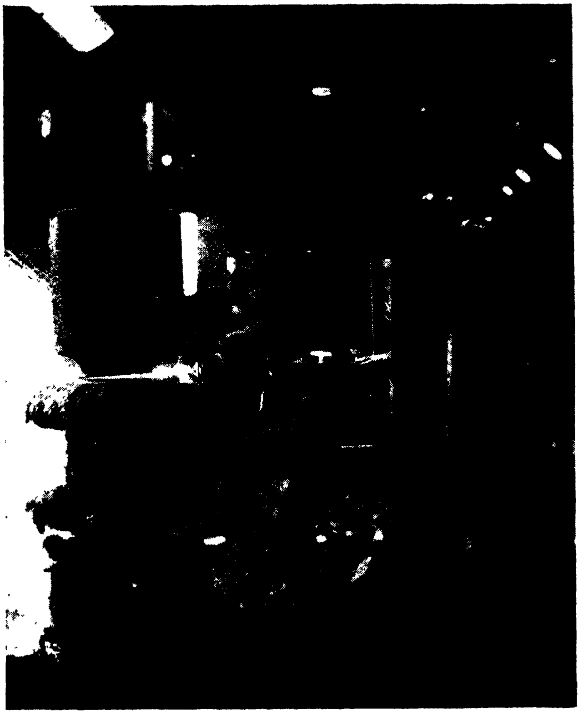


FIG. 18.—AUTOMATIC FLAME-CUTTING EQUIPMENT IN USE FOR REMOVING FEEDER HEADS FROM LARGE STEEL CASTINGS

is removed on the knock-out, a considerable amount still adheres to the surface and in crevices and pockets, and the interior is often full of tightly packed core sand. Thus, the first stage of fettling is to remove this sand, much of which can be loosened by rapping the casting with a hammer. In larger foundries, however, a mechanical means of sand removal, such as shot blasting or the hydro-blast system, is generally employed.

The principle of the shot-blasting process is to discharge steel shot or grit through a nozzle at a very high velocity by means of compressed air or other means, the abrasive action of the shot removing the sand or scale. The direction of the stream can be controlled, allowing it to be directed uniformly over all parts of the casting exterior and interior, with the result that parts normally inaccessible by ordinary hand cleaning or tumbling methods can usually be reached.

Hydro-blast System

During recent years there has been considerable development of the wet cleaning process, which offers several important advantages over shot blasting, including the elimination of dust. This process uses a mixture of high-pressure water and sand, and is claimed to be capable of removing hard and complicated cores in addition to cleaning sand from the casting surfaces. The system is so designed that the core and moulding sand may be reclaimed either for moulding purposes or for re-use in the system.

The plant is more expensive than ordinary shot-blasting equipment, and thus—from an economic viewpoint—its installation is controlled largely by the output of the foundry. The makers claim that its installation is an economical proposition if the output exceeds 10 tons per day, and if the castings are

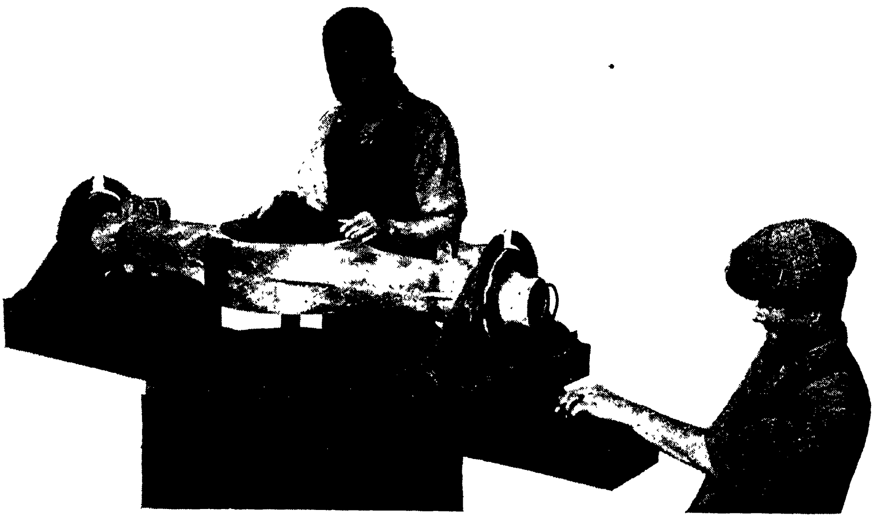


FIG. 19.—A SPECIAL FIXTURE DEVELOPED FOR CHECKING THE VARIOUS SURFACES OF A CAST AUTOMOBILE REAR-AXLE CASING

sufficiently intricate to make difficult the employment of shot blasting. The mixture is discharged through a gun carried on a flexible hose, the gun being easily handled by one man. A fine stream of sand and water is projected against the casting at a pressure of 1,200 lb. per square inch, and with a velocity in the region of 16,000 ft. per minute.

Tumbling

Another method of cleaning the surface of castings is by "tumbling," an operation which produces extremely good results, although, compared with shot blasting, it is very slow. For high-quality work, however, this slowness is advantageous, as it results in the work surfaces being given a polished, burnished finish arising from constant rubbing together of the castings. Much of the "flash" metal is broken away, thereby considerably reducing subsequent fettling. As a rule, the output of the foundry, size of the castings, and the quality of finish desired are the deciding factors as to whether the choice should be tumbling or shot blasting. Various special types of tumblers have been developed, one of which combines the tumbling and airless shot-blast processes.

INSPECTION

To ensure that the quality of inspection is not prejudiced by any other considerations, inspection personnel should never be under the direct control of any department concerned with production. It is important that the inspector should always have ready access to correspondence referring to specifications,

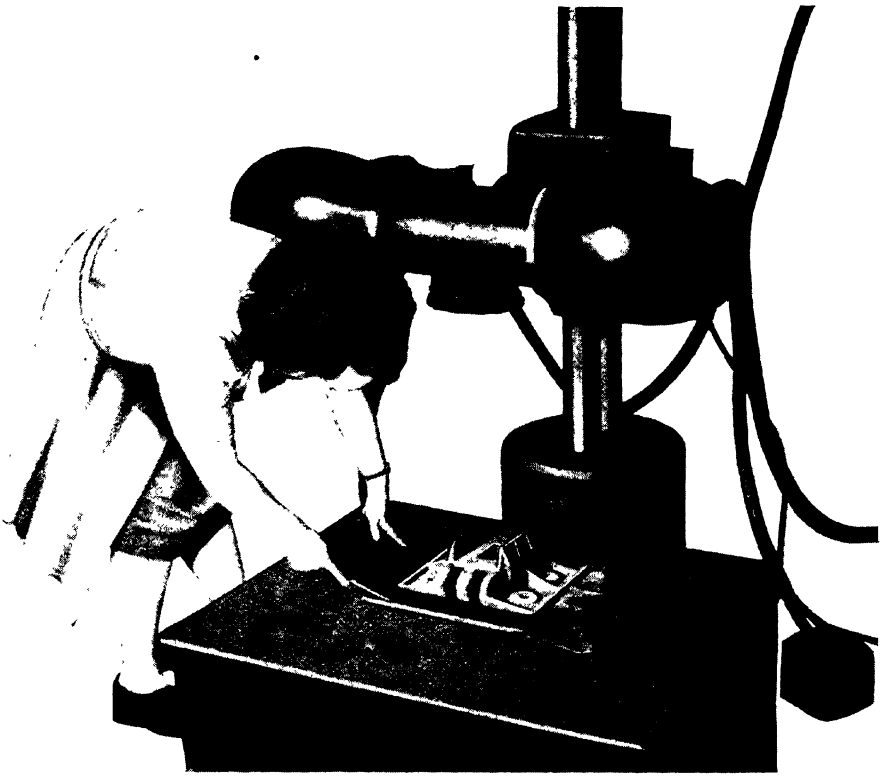


FIG. 20.—PREPARING A " FIRST OFF " CASTING FOR EXAMINATION WITH X-RAY EQUIPMENT IN ORDER TO ENSURE THAT THE CORRECT FOUNDRY PROCEDURE IS BEING EMPLOYED

giving important dimensions or mentioning any particular features relating to the use to which the casting is to be put when in service.

Form and Dimension

The methods employed for checking the form and dimensions are very largely governed by the quantities involved. In the case of single castings or very small numbers, ordinary marking-off table technique is normally used. For larger quantities time may be saved by making a template from tin, wood, or cardboard.

The employment of fixtures (Fig. 19) for checking purposes undoubtedly provides the best solution for an economical, quick, and accurate means of dealing with medium and large quantities. Those for checking form or profile often incorporate one or more sheet-metal templates cut to the desired shape: they may be very simple and intended for checking only one contour, or could be more complicated in order to deal with several surfaces simultaneously.

Choice of Locating Surfaces

The choice of the locating surfaces in the fixture is a question of paramount importance. Wherever possible, these should be taken from reliable "static" pattern-produced surfaces in preference to those left by a core or insert—which are liable to vary slightly in position relative to the mould. The customer can contribute towards the accuracy of inspection by indicating on his drawings which surfaces will be used for gripping or locating purposes during machining operations, so that they may also be employed for location in the checking fixture, thus ensuring that the casting will "clean up" correctly when machined. In addition, attention should be drawn to the relationship between any special datum lines and surfaces, so that the fixture may be designed to check these also.

Mechanical Properties

Another important branch of inspection is concerned with checking the mechanical properties of the metal. When this is specified by the customer, test pieces are cast integral with the casting or, alternatively, test bars poured at the same time as the casting. From these, vital information may be obtained regarding the tensile strength, yield point, elongation, and reduction of area. In the case of castings required for special purposes, hardness, impact, torsion, fatigue or corrosion tests may also be requested.

Sometimes the customer may specify maximum or minimum limits for certain constituents in the metal, and this necessitates chemical analysis in the laboratory. Study of the microstructure may also be requested to ensure that heat-treatment has been correctly carried out.

Internal Inspection

For internal examination the choice lies between destructive inspection and the use of X-ray or gamma-ray equipment (see notes on page 30), the latter suffering from the disadvantage of high initial and running costs. With large castings in particular this means that it is not economical to inspect every portion.

Although not specified for general use, radiographic inspection (Fig. 20) is essential in some instances, particularly in the case of castings for the aircraft industry, or those likely to be subjected to very high pressures or stresses in service. The most simple form is the screening process, which has the advantage of enabling immediate examination of the specimen without having to wait for the development of plates or film. For heavier and large-section castings, the photographic process is essential.

It is normal practice, in foundries equipped with X-ray plant, to test sample or pilot castings radiographically, and to adjust methods of running and feeding in the mould until consistent soundness is obtained. This is much cheaper and more satisfactory than waiting for large numbers of castings to show defects in the machine shop.

For the examination of heavy-section steel castings, e.g. over 4 in. or so thickness, resort is generally made to gamma radiation, radium being the usual source. Radium is also employed for the inspection of castings of lighter section than 4 in., because of the relatively large number which can be examined at any one time. Radon, a gaseous decomposition product of radium also employed as a source of gamma radiation, has the advantage of being portable and possessing high powers of penetration. It is, in fact, somewhat superior to radium in the quality of its radiographs, but possesses the disadvantage of a short effective life not exceeding a few days.

Pressure Testing

Pipe castings and hollow vessels of all kinds are frequently subjected to pressure testing, generally hydraulic. In cases where the bore has subsequently to be machined, even if by the customer, it is sound policy for the founder to take a rough cut over the surface prior to testing, as this aids disclosure of any hidden defects likely to cause rejection at a later stage.

HEAT-TREATMENT

For cast iron there are three main stages of heat-treatment, these comprising: (1) the high-temperature treatment to alter the constitution of the metal, as, for example, when malleabilising; (2) stress relief annealing; and (3) quenching and tempering to improve the physical properties. The two most common methods of producing malleable cast iron are the Blackheart (American) process, and the Whiteheart process employed in Europe. For the former, the castings are packed in containers and gradually heated to a temperature up to 1,000° C., held at this figure for 3–6 days, and then allowed to cool slowly. With the Whiteheart process, special white iron castings are used, these being packed in containers, together with a mixture of hematite ore, and gradually heated to approximately 900° C. They are held at this temperature for 5–6 days, and then slowly cooled. In addition to these two methods, a variety of modified techniques are also employed.

As the name implies, stress-relief annealing is employed for releasing locked-up stresses, the cause of which has been already mentioned. The process consists of slowly heating the castings to 450–550° C., and holding them at this temperature for a period corresponding to approximately one hour for each inch of casting thickness.

The third type of heat-treatment is introduced to improve the properties of the casting, i.e. hardness, toughness, etc. To obtain special properties, certain alloy elements, particularly nickel, are added to the iron, and thus the type of treatment employed varies according to the composition of the steel. In general, it consists of heating the metal to a suitable temperature and then quenching in water. A typical example of this is provided by the flame-hardening process widely used for hardening the surface of cast-iron machine beds, etc.

Steel Castings

The heat-treatment of steel castings is complicated by various factors, such as size, shape, properties required, and steel composition. In the case of steel, heat-treatment is employed for two main purposes, one being the relief of internal stresses introduced during cooling of the casting, and the other the improvement of the properties of the material by refining the grain and homogenising the structure, so providing certain physical and mechanical qualities which vary according to the structure of the steel. As a rule, heat-treatment is performed after fettling, although certain exceptions are provided by alloy steels.

Non-ferrous Castings

There is very little use of heat-treatment in the non-ferrous foundry. One of the few processes employed is the "precipitation hardening treatment" applied to certain types of aluminium alloy, special brasses, bronzes, copper and nickel alloys. Briefly, the process consists of quickly cooling the casting, then reheating to an intermediate temperature, when precipitation of certain insoluble constituents take place in the metal. After completion of precipitation, the castings are cooled to room temperature. In effect, the process comprises a speeding-up of the well-known "ageing" process (see page 29).

Acknowledgment is given to the British Steel Founders' Association for the provision of data and the loan of illustrations used in this chapter.

J. A. O.

FOUNDRY MECHANISATION

UNDER present-day conditions of intense competition, it is more than ever essential to produce castings at the lowest possible price. Assuming that the actual manufacturing processes are being performed in the most economical manner compatible with good-quality work, the only way left to reduce costs further is to lower material handling charges by avoiding the use of expensive manual labour wherever possible. This necessitates the employment of mechanical handling equipment.

Economic Considerations

The installation of mechanical handling equipment involves a heavy initial expense, although, once installed, the operating costs are much lower and output much higher than if the same work was performed by manual labour. Consequently, careful consideration is necessary to determine whether the advantages to be gained warrant the expense involved.

If the foundry is engaged with long "runs" of repetition work, mechanisation is nearly always an economic proposition. On the other hand, in general, mechanisation is not to be recommended for "jobbing" work, i.e. if the foundry is occupied with the production of single castings or small batches of similar castings. There are, naturally, exceptions to this rule: for instance, the size, shape or nature of the work may occasionally prevent mechanisation even if fairly large quantities are involved. In the case of old buildings, the layout may not permit full mechanisation in an economic manner, although compromise by partial mechanisation may provide a solution.

Opinions differ considerably as to the size of "run" necessary before mechanisation becomes an economic proposition. In addition to a survey of existing conditions, it is essential to consider the future policy of the foundry when contemplating mechanisation. Is the trend of conditions in the market served by the foundry likely to lead to large orders for repetition work, or is there a tendency towards smaller quantities? Is it worth while entering the "mass production" market more deeply, or is it advisable, instead, to build up a reputation as a specialist foundry capable of producing difficult castings required only in small quantities? These, and many other factors, must be considered when making the decision.

During recent years there has been a gradual change of opinion regarding the size of output necessary to make mechanisation profitable. In the past, it was not considered practicable unless the foundry was engaged almost entirely with long runs of repetition work in the region of 50,000 or more per time, and

FIG. 1.—GENERAL VIEW OF LIGHT SECTION OF FOUNDRY, SHOWING MECHANISED MOULDING CONVEYOR AND CONTINUOUS CASTING
(*Marshall, Sons & Co., Ltd.*)

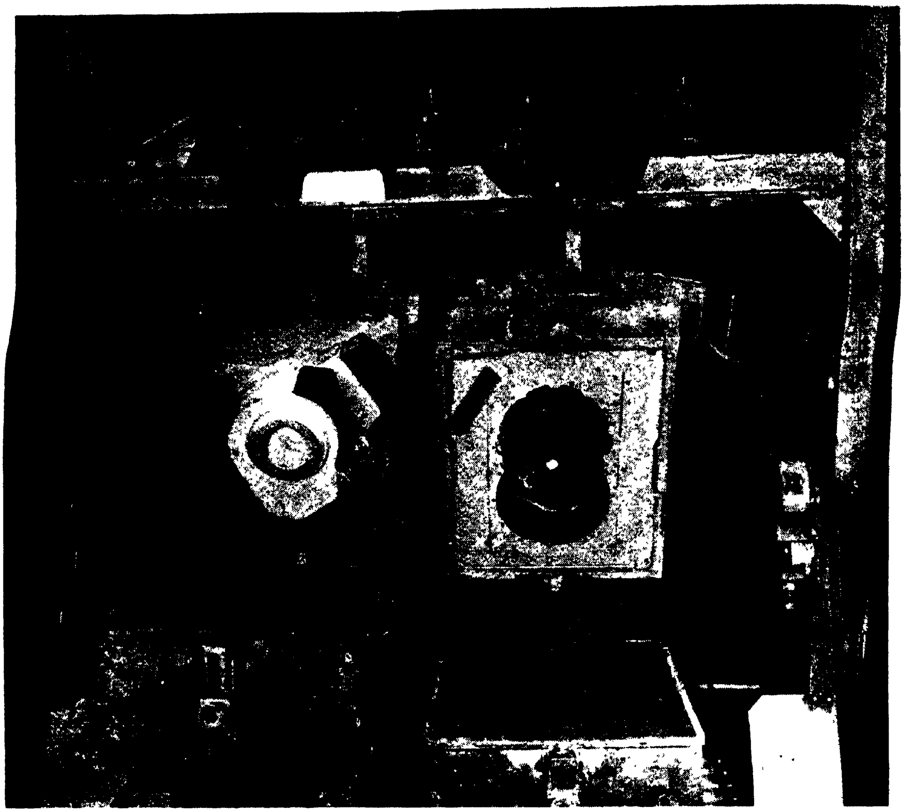


FIG. 2.—HERMAN-PNEULEC 4,000-LB. MOULDING MACHINE, SHOWING PATTERNS WITHDRAWN FROM THE DRAG AND COPE (*Marshall, Sons & Co., Ltd.*)

this is still recognised as being the ideal condition for mechanisation. However, it is now realised that, if carefully planned, mechanisation can be equally advantageous for jobbing work involving "runs" as small as 50–1,000 castings per time. The layout of such a foundry will be described later.

Movement of Materials

In the foundry, mechanisation falls under two main headings: (*a*) the production of cores and moulds by machines instead of by hand; and (*b*) the transport of materials and other items by mechanical means. The former is covered thoroughly elsewhere in these volumes, and thus can be ignored here.

Many tons of materials must be moved for each ton of castings produced. These include moulding sand, core sand, empty moulding boxes, closed moulding boxes, moulding boxes after pouring, waste sand after "knocking out," the castings, scrap metal, and materials for the furnace or cupola. During a single

week, the amount of material moved in a medium-size foundry can easily be in the region of 500–1,000 tons. Thus, it will be obvious that reduction in handling costs can prove an important factor in foundry economy. *Equally important is* the fact that the high output provided by machine moulding and core making makes speedy transport of materials absolutely imperative if the shop processes are not to become completely unbalanced.

FIG. 3.—SECTION OF THE KNOCK-OUT DEPARTMENT, SHOWING STERLING VIBRATORY SHAKER-OUT (*Marshall, Sons & Co., Ltd.*)

SAND HANDLING

One of the most important problems is that concerned with handling the various types of sand for moulding and core making, and the used sand after knocking out. In the modern mechanised foundry, a single "unit" or "reclaimed" sand is generally employed for moulding purposes, this comprising "used" sand treated to restore it to a condition suitable for re-use. For iron work, the entire mould may be made of "unit sand," whilst in steel foundries it is often employed only as "backing" material, new facing sand being added in the proximity of the pattern impression. In a busy mechanised foundry, the same sand may be used three or more times each day.

Sand Reclamation

After pouring and cooling, the moulds are knocked out over a grating, the sand and smaller pieces of metal falling on to a wide, troughed conveyor belt housed in a tunnel below. The actual layout of the system varies with local conditions, but in many cases there is a single knock-out station at the end of the cooling section (Fig. 5). On the other hand, a long grating sometimes runs full length across the ends of a number of tracks.

Occasionally, it may be possible to run the belt direct from the knock-out grid to the sand plant, but in most installations two or more changes of direction are necessary because of intervening plant. In such cases, the belt discharges on to a second belt (Fig. 15), which, in turn, may possibly discharge on to a third, or even a fourth. Each belt is driven by a separate motor and reduction unit, giving a speed suitable for the amount of sand to be handled. As a guide, it may be mentioned that in one particular foundry these belts run at 100 ft. per minute.

It is nearly always necessary to raise the sand to 15–30 ft. in order to discharge it into the sand treatment plant, and this may be done in two ways. Either the last belt may be sloped upwards or, as is more usual, the last belt discharges the sand at the foot of a bucket-type elevator which raises and discharges it into a hopper.

Typical Installation

An arrangement of a typical sand plant is shown in Fig. 4. Approximately 25 tons of sand are in constant circulation through this plant. Additions of new

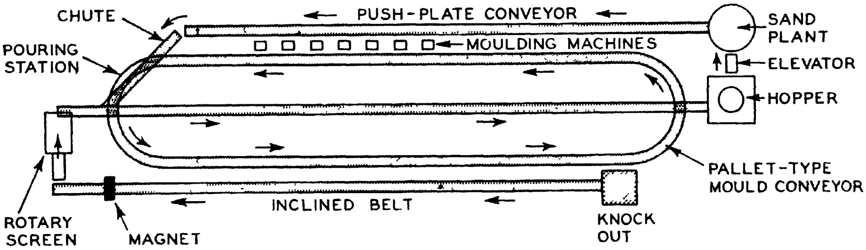


FIG. 4.—ARRANGEMENT OF SAND PLANT IN A HIGHLY MECHANISED IRON FOUNDRY

material are made at regular intervals to keep it up to standard: in a twenty-four-hour day, the same sand is used approximately six times. Since the used sand contains a large proportion of "fines" or dust produced by the burning action of the hot metal on the sand, and most of the moisture is removed by the action of the heat, constant analysis of the sand must be made at hourly, or even half-hourly, intervals.

At the knock-out station, the used mould sand falls on to a troughed belt, which rises at a fairly steep angle from below floor level to discharge into a rotary screen mounted in the roof trusses, where hard burnt lumps of sand and other foreign material are removed. On the way up, the belt passes under a magnetic separator which removes any broken core irons or pieces of tramp metal. At the exit end, the screen discharges the sand through a chute on to a long overhead belt which returns it to a storage hopper situated at the opposite end of the plant (see Fig. 4). At intervals, the sand is discharged from the bottom of the hopper into a bucket elevator, and raised approximately 20 ft. to the top of a tower-type sand plant, where it is sprinkled with water, milled, and disintegrated ready for redistribution to the moulders.

The reclaimed sand is now discharged on to a "push-plate" or "scraper" conveyor running above the moulding machines. This comprises an endless chain with a series of flat steel scrapers which push the sand along a steel trough. In the base of the trough is a series of holes, one for the hopper of each moulding machine. As the operator releases the sand to his mould, the level in the hopper falls, leaving a space at the top which is automatically filled by the sand as it is scraped along the trough. Any surplus sand discharges over the end of the trough into a chute feeding the return belt conveyor bringing the used mould sand back to the reconditioning plant.

Core Sand

Compared with moulding requirements, the amount of sand necessary for core-making purposes is relatively small. Thus, except in the larger foundries, special handling plant is not employed. Also, because new sand is always used for cores, the question of reclamation does not occur. Incoming sand is usually stored in hoppers or bins and transferred to the core-making department by barrow or skip, suitable amounts being placed in bins adjacent to each bench. Before use, core sand requires treatment to give it the correct properties.

Where, because of the large output of cores, considerable amounts of sand are required, a mechanical sand-handling system can be installed. Even then the amounts are comparatively small, and thus the plant differs entirely from that employed for moulding sand, as may be gathered from the following description referring to a large steel foundry.

Prior to use, the core sand is thoroughly dried in a rotary gas-heated drum which is fed by a 20-cwt. capacity skip raised up inclined rails by means of cable. At the top of the rails is a switch which provides a pause of sufficient duration to allow the skip to empty its contents into the hopper below, the skip then descending the rails until a trip switch causes movement to cease. Thus, the operation is completely automatic apart from shovelling the sand into the skip.

It is necessary to deliver a continuous supply of this sand to storage hoppers situated approximately 170 ft. away and mounted in the roof of the foundry. This problem has been overcome by the installation of a pneumatic sand transporter. This comprises a cyclone fan which blows into the end of a 9-in. diameter pipe: a few feet from the end is a funnel into which the sand discharges from the dryer. Thus, as it falls into the pipe, the sand is blown for a distance of 170 ft. to the hoppers. The rate of sand feed may be varied by means of a valve controlling the amount of air delivered by the fan.

MOULDS AND CORES

The layout of mechanised moulding departments is governed largely by the shape and area available, as well as the size of the work, rate of output, and other factors, and thus no hard-and-fast rules are possible. The main guiding principles are to reduce operator fatigue to the minimum wherever possible by avoiding lifting and carrying, save floor space, and ensure a steady, balanced flow of moulds in a forward direction.

A variety of track layouts are possible. For instance, it is quite common practice to group the moulding machines in pairs to produce drags and copes respectively for the same mould (Fig. 5 (*a*)). These could be served by three roller tracks, drags being placed on one outer track and copes on the other outer track; farther along the system, the boxes would be lifted on to the centre track for closing. Such an arrangement, however, raises difficulties regarding the return of empty boxes to the moulding machines, and necessitates storing them at the side or rear, thus hindering movements of the operators.

A more efficient scheme (Fig. 5 (*b*)) would be for the operators to place the top and bottom moulds alternately on the centre track, which would also be used for closing and filling. After knocking out, the empty boxes return to the machines via the outer tracks, which also serve as a storage buffer. One foundry provides four tracks for each pair of machines (Fig. 5 (*c*)). The tops are placed on one of the inner tracks and bottoms on the other. After insertion of the cores, etc., the tops are lifted on to the bottoms for closing, and the complete mould then continues along the track for pouring. The two outer tracks slope towards the machines, and are used for the return of empty boxes.

In every layout the tracks are also used for storage purposes, and thus must be sufficiently long to accommodate a good supply of boxes and moulds. If it is used also for pouring—as is generally the case—it is desirable to be able to store enough moulds to receive the entire contents of the ladle or heat. Only in very rare instances is it possible to use power-driven conveyors, because of the necessity for very accurate synchronisation of operations.

For comparatively heavy work it is more suitable to have a single gravity

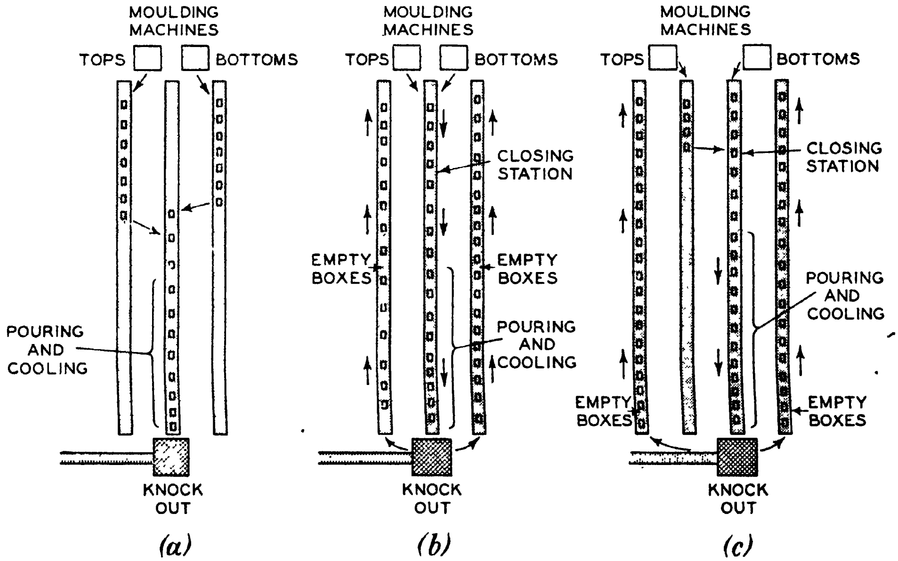


FIG. 5.—THREE TRACK LAYOUTS FOR THE MOULDING DEPARTMENT

FIG. 6.—PENDULUM-TYPE CONVEYOR IN A CORE SHOP (*Ford Motor Co., Ltd.*)

roller track leading from the machine to the pouring station. The box can then be pulled or lifted straight from the machine on to the conveyor, along which it is moved for core setting, closing, or similar operations. The conveyor should be sufficiently long to enable a stock of moulds to accumulate, so that the complete batch can be filled from one ladle of metal. In such a case, lifting tackle would be provided for transferring the top mould and lowering it on to the bottom box.

In highly mechanised foundries equipped with an oval, continuous system (Fig. 12), pallet-type conveyors are employed. These comprise a number of sheet-steel pallets or plates towed by an endless chain, and usually arranged much nearer to the ground than other types. They are capable of handling comparatively large and heavy moulds, but are only used for continuous operation, as will be described later.

The Core Shop

Essentially, the work in the core department consists of making the core, baking or drying it to the requisite degree of hardness, and then inspecting the finished product. These three main operations control the layout of the handling equipment. As mentioned earlier, the sand is usually placed in bins adjacent to each core-maker's bench, and thus the first stage of mechanical handling can only concern transport of the "green" cores to the drying stoves. For this, two systems are in general use—flat-top band or belt conveyors and pendulum-type conveyors; gravity-type roller tracks are not very widely employed because of certain drawbacks, particularly vibration, which may damage the fragile cores in the "green" state.

With flat-topped conveyors, the department is usually arranged with the benches on each side of the continuously moving conveyor—which leads to the drying oven—the core makers placing their work on it as completed (Fig. 7). Often, to reduce chances of damage, the cores are stacked on flat, perforated metal plates, on which they remain for all subsequent stages. The conveyors may consist of a wide endless steel band or an ordinary rubber-canvas belt, and at the discharge end the core plates run on to a level steel top, from where they are transferred by hand to the drying oven.

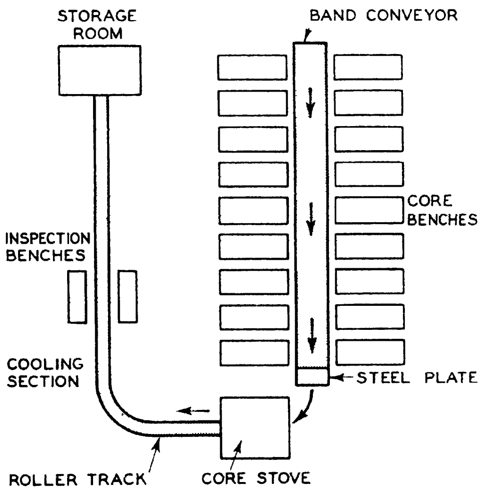


FIG. 7.—ARRANGEMENT OF EQUIPMENT IN A CORE SHOP

Pendulum-type or chain conveyors are entirely different, consisting of trays suspended from an overhead endless chain. The conveyor encircles the core benches (Fig. 8), and is within easy reach of each operator. The drying oven is also situated adjacent to the conveyor, and as the trays pass the opening the cores are transferred to the interior by hand.

Drying Stoves

If the cores are large, they will most probably be dried in a brick-built, fixed type of oven. With such installations, the cores are placed on movable steel racks or shelves situated adjacent to each bench, these being transferred to the interior of the oven by means of a lifting truck. Although it would be possible to load the racks at the discharge end of a flat-top conveyor, such a system would not be very usual.

For small- and medium-size cores, such as are normally made in a mechanised department, drying is done in a continuous-type stove.

The vertical type of stove comprises a series of wire-mesh or perforated-steel trays or shelves suspended between two endless chains running over large sprocket wheels arranged at the top and bottom. The system is enclosed in a sheet-metal housing having an opening at each side; these are the loading and unloading stations. By means of fans and suitable heating equipment, warm air is circulated around the interior to dry the moving cores, the speed of chain movement and the temperature of the air being so adjusted that the cores are dry when they reach the unloading opening.

The trays move continuously and do not stop for loading and unloading. As the length of time required for drying a core is mainly governed by its size

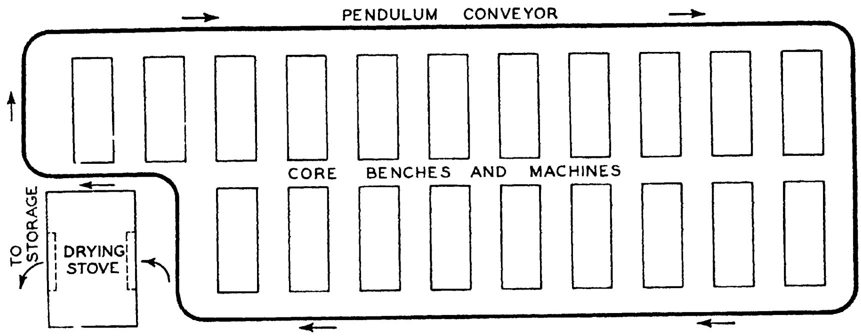


FIG. 8.—TYPICAL LAYOUT FOR A CORE SHOP SERVED BY A PENDULUM-TYPE CONVEYOR

and shape, to ensure efficient drying it is always desirable to load the oven with work of approximately similar dimensions and contours. When this is not possible, it may be necessary to allow larger cores to make a second circuit of the store.

Inspection

The route followed after unloading from the drying stove varies from foundry to foundry. In one foundry (Fig. 7), the trays of cores are placed on a gravity roller track arranged at the same height as the unloading station, and then pushed by hand towards the inspection section. As the cores are considerably stronger after drying than when in the "green" condition, they are not so liable to damage from vibration arising from the rollers.

The length of track is sufficient to allow the cores to cool before handling. Simple cores are inspected whilst still on the track, the more complicated types being removed to adjacent benches. After inspection, the cores continue along the conveyor to a large, heated chamber, where they are stored, free from moisture, until required for use, when they are then transferred by rack or truck to the appropriate station on the mould closing line.

FIG. 9.—LOADING SIDE OF A CONTINUOUS CORE-DRYING OVEN (*Ford Motor Co., Ltd.*)

METAL MELTING

Comparatively little mechanisation is possible for handling cupola fuels and materials, which are usually loaded in skips or bogies, and handled by crane. In most of the heavier foundries, the molten metal is tapped into a ladle and then transported by overhead crane to the pouring station.

Others adopt a system similar to that shown in Fig. 11. Here, a light overhead monorail leads from the cupola to the pouring section, where the moulds are arranged on the floor or track in straight lines. After passing backwards and forwards along the rows, it returns to the cupola in a continuous and unbroken circuit. If desired, branch rails leading to sections engaged with hand moulding can easily be connected to the circuit by means of switches. Suspended from the monorails on rollers are several ladles, usually of the bottom-pouring type or tilting lip-pour style, which move along the rows to fill the moulds. When empty, they continue in the same direction for return to the cupola for refilling.

When the foundry layout necessitates pouring from a fixed station, as in the case of a continuous oval track (Figs. 4 and 17), an arrangement as shown in Fig. 12 is often employed. Here, a light monorail connects the cupolas and pouring station in an endless circuit, and carries one or more ladles of metal.

THE FETTLING DEPARTMENT

In general, there does not appear to have been any wide-scale attempt to mechanise the fettling department, apart from the provision of mobile trucks or the use of bogies on a rail running centrally through the shop. One of the comparatively few exceptions is provided by the layout shown in Fig. 13.

This particular department is very long and rather narrow, and running completely from one end to the other is a 94-ft. long gravity roller track mounted

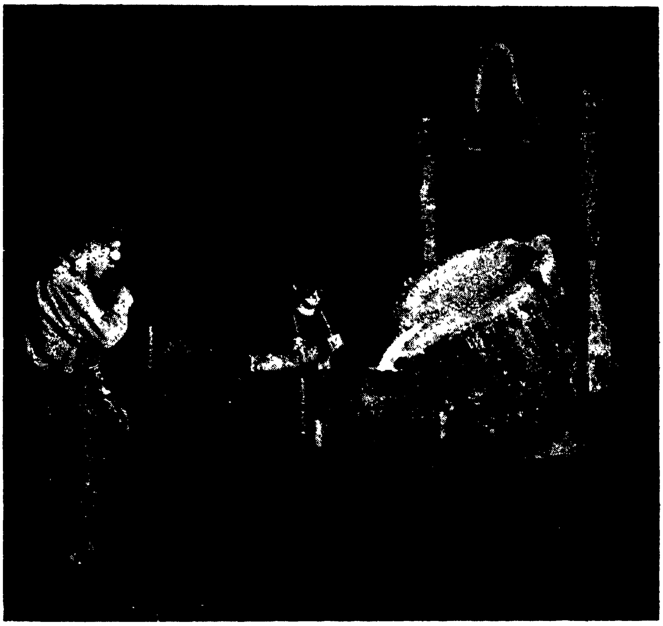


FIG. 10.—CASTING IN THE MEDIUM-HEAVY SECTION OF A MECHANISED FOUNDRY

The ladles are handled by means of overhead cranes. (*Marshall, Sons & Co., Ltd.*)

15 in. above ground level. At the exit end of the shop, the track curves away to the final inspection section and the despatch department. Arranged on each side of the track are the saws, grinding machines, and benches where the various fettling operations are performed, and between each of these is a short length of fixed roller track, placed at right angles to the main system. These terminate 2 ft. from the main track, thus leaving room for workmen and shop cleaners to move about.

Let into the floor on each side of the central roller track, and parallel with it, are rails on which run small bogies carrying a sturdy framework and five rollers similar to those on the main track: in effect, the bogies carry a 2-ft.

FIG. 10A.—STEEL CASTING IN A MECHANISED FOUNDRY
The ladle is handled by means of an overhead crane. (*Marshall, Sons & Co., Ltd.*)

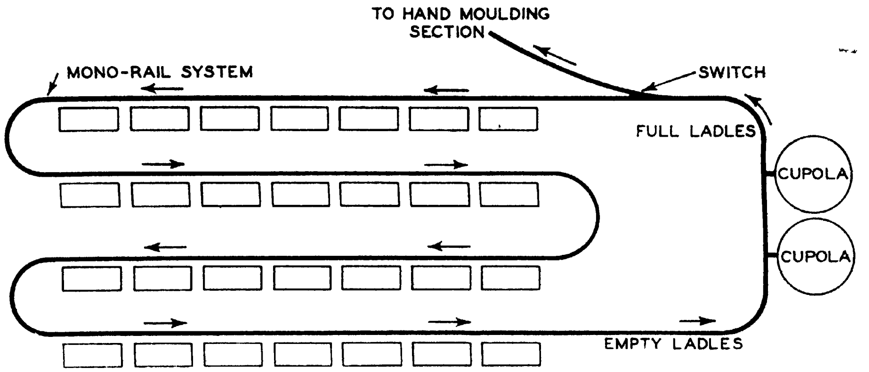


FIG. 11.—EMPLOYMENT OF AN OVERHEAD MONORAIL FOR TRANSPORTING LADLES OF METAL ALONG THE LINES OF MOULDS

length of transfer roller track which is moved along the rails to bridge the gaps between the main central track and the short auxiliary tracks leading between the machines and benches. Provision is made to locate and lock the bogies quickly in their respective positions. By this means it is possible to direct the heavy skips containing castings to any machine or bench without lifting them. Also, it is an easy matter to bypass any container without lifting it from the track. To reduce fatigue further, the heavy skips of castings are brought from the knock-out station on an overhead monorail system.

At the end of the fettling department, the track passes through an opening in the wall to a small shop, where the castings and waste metal are weighed, and the castings given final inspection. To avoid lifting, a section of the roller track is mounted on the platform of the weighing machine at the same height as the main system. Thus, it is only necessary to push the containers on and off the weighing machine. Finally, the track then continues to the despatch department situated outside the main building.

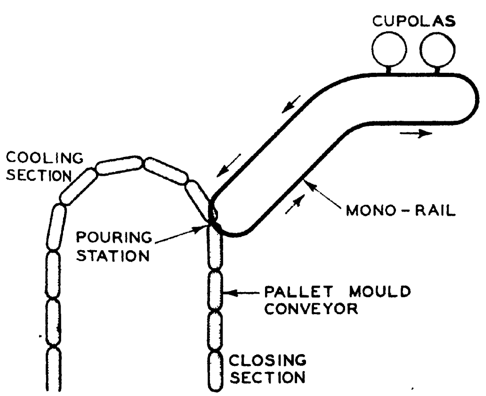


FIG. 12.—SCHEME OFTEN ADOPTED FOR FEEDING A FIXED POURING STATION, AS ON A CONTINUOUS TRACK

COMPLETE INSTALLATIONS

Although in small foundries only one or two of the various departments may be equipped with mechanical handling equipment, in large foundries it is the general practice to blend them together into a com-

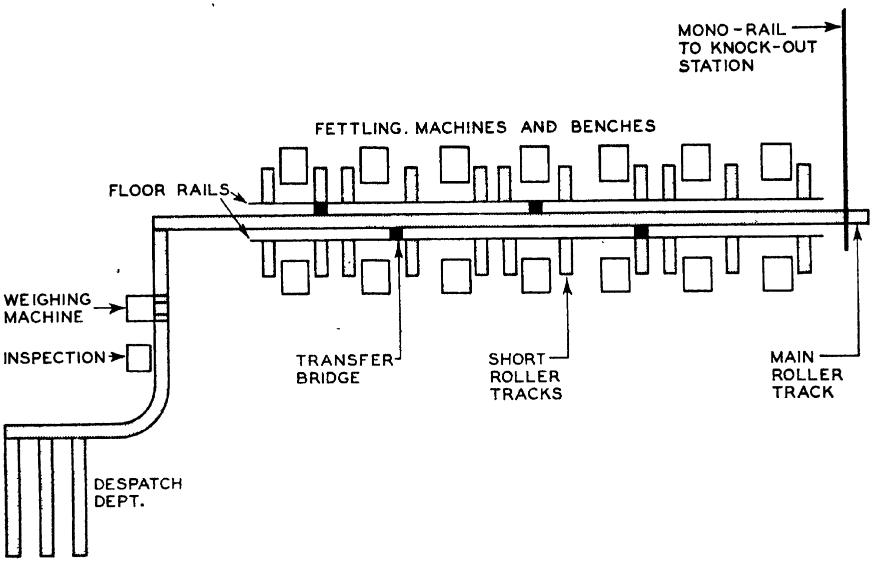


FIG. 13.—FETTLING SHOP LAYOUT WHICH REDUCES OPERATOR FATIGUE BY MINIMISING THE NEED FOR LIFTING THE CASTINGS

plete installation serving all sections. Careful planning is necessary in order to ensure balanced production, as it will be appreciated that complete chaos could result if any part of the system was unbalanced.

Mechanised Moulding Department

Fig. 14 shows the neat and very simple layout employed in the moulding department of a mechanised mass-production steel foundry. From each machine is a straight gravity roller track leading to a common closing and filling track arranged at right angles. Near the end of each machine track is a special gas-fired dryer, under which the mould remains for a prescribed period for skin drying. Each adjacent pair of machines is arranged to produce top and bottom moulds respectively, and thus it is an easy matter after drying to lift them alternately off the machine tracks on to the closing and filling track. As closed, they are pushed towards the pouring station and, after filling, move along the cooling section, falling over the end on to the knock-out grid. The boxes are returned to the machines on hand-propelled trucks, the short distances involved making the use of conveying equipment unnecessary.

The used sand falls on to a 24-in. wide belt conveyor running underground for the full length of the foundry and discharging on to an 18-in. belt, incorporating an overband magnetic separator for the removal of tramp metal. This latter belt feeds a bucket elevator, which raises the sand and discharges it into a rotary screen for the removal of hard lumps; these fall down a chute into a bin, the screened sand falling into a storage hopper.

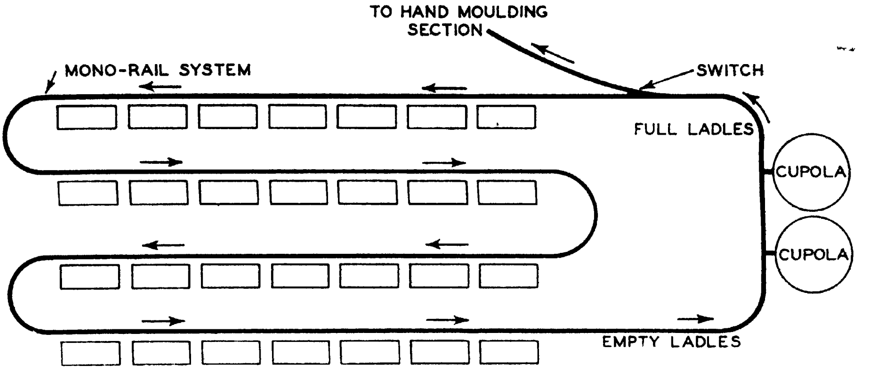


FIG. 11.—EMPLOYMENT OF AN OVERHEAD MONORAIL FOR TRANSPORTING LADLES OF METAL ALONG THE LINES OF MOULDS

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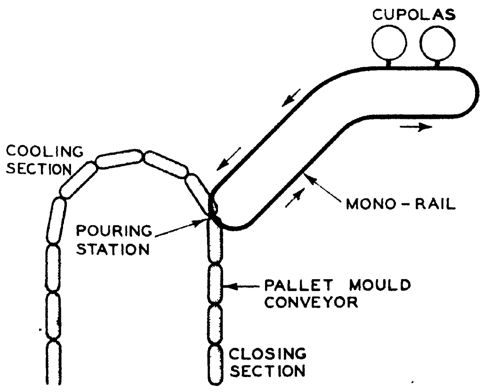


FIG. 12.—SCHEME OFTEN ADOPTED FOR FEEDING A FIXED POURING STATION, AS ON A CONTINUOUS TRACK

COMPLETE INSTALLATIONS

Although in small foundries only one or two of the various departments may be equipped with mechanical handling equipment, in large foundries it is the general practice to blend them together into a com-

output of this foundry is in the region of 50–60 tons, i.e. 4,000 finished steel castings per week.

The influence of the size of the batch on the economic working of the foundry is illustrated by the following production figures. With a team of five men, the peak output of a long run, i.e. a very large batch, is approximately 300 moulds per day, this falling to an average of 150 moulds per day for short runs of work. The output of cores is also influenced in a similar manner. From this it will be seen that, in comparison with foundries of similar size engaged entirely on long runs, output is approximately halved solely by the smallness of the batches and the varied nature of the work.

As regards moulding equipment, this requires to be particularly flexible. Whilst expensive special-purpose set-ups suitable for one job only would undoubtedly reduce production times in the mass-production foundry, they would prove uneconomical for jobbing work. On the other hand, the fact that all the labour is either unskilled or semi-skilled necessitates the employment of certain 'mass-production" principles.

Although it is necessary to have a fairly wide range of pattern plates, consideration must also be given to such factors as the number of moulds per hour produced on the machine, storage accommodation for moulds, metal supply, and storage space for empty boxes.

Core and Mould Making

The layout of a foundry designed for short runs of work is shown in Fig. 15. All core making is done entirely by female labour, the output being in the region of 6,000–8,000 cores per week in sizes ranging from a few ounces up to 56 lb. Most of the work is hand rammed, although, where shape and quantities permit, output is considerably increased by the use of core-blowing machines. Completely encircling the department, and passing all tables, is a pendulum-type conveyor which carries the cores to a continuous vertical gas-fired stove. After drying, the cores are stacked on mobile racks and transported to the moulding section.

The moulding machines operate in pairs, one producing the drag or bottom half, and the other the cope or top half, most pairs of machines being served by three straight gravity-type roller conveyors. As completed, the drags and copes are placed alternately on the centre track, where they remain for closing and filling; after pouring and knocking out, the empty boxes return to the machines via the two outer tracks.

One pair of machines is reserved for larger types of work, and thus, because of the heavier boxes in use, a slightly different conveyor layout is employed. In this case, the drags are placed on the central track and the copes on the adjacent track, the latter being later transferred to the central track for closing purposes by means of lifting tackle carried on a short runway spanning both conveyors. The moulds then move along the track for pouring, this being followed by stripping over a grid with pneumatic vibratory knockout equipment. Finally,

the empty boxes continue along the track to return to a position where they are easily accessible for re-use.

The smaller boxes from the other lines are stripped over a long grating in the knockout section, using overhead mobile vibratory equipment which can be moved from track to track. It will be noticed that the conveyor system includes transfer sections across the ends to enable the moulds to be moved with minimum effort to the knock-out section, or to be switched from one track to another. The empty boxes are then returned to the machines by the reverse route.

At the knockout station the sand falls through the grating on to a belt system below and is transferred to the sand reclamation plant, where it is prepared for re-use. Since the sand is used two or three times daily, very close laboratory control is maintained, approximately twenty checks being made each eight-hour shift.

For pouring, the ladles of steel are transported by overhead cranes to the conveyor lines, where the boxes are laid ready to receive the steel. In this particular foundry, teapot-type ladles are employed, and as many as 100 moulds can be filled from one "heat" in a period of 30–40 minutes.

High-speed Casting

An outstanding example of the efficient use of mechanical handling equipment in a high-speed mass-production foundry is provided by the layout in Fig. 17. This particular department is engaged solely with the manufacture of cast-iron pipes for the building industry, the output being approximately eight pipes per minute, the pipes varying in length up to 6 ft.

The general layout of the foundry is as follows: surrounded by an oval-shaped pallet-type conveyor are four sand-slinging machines, each being mounted in the centre of a rotary grid-type table arranged at floor level. Nos. 1 and 2 slingers are engaged with the production of the top half of the moulds, whilst Nos. 3 and 4 produce the bottom half, each slinger ramming 30 tons of sand per hour.

The mould conveyor comprises 46 steel-topped pallets with a towing chain passing through the centre line. It is driven by two 7½-h.p. motors which, by means of gear-reduction units, provide speeds variable between 6–18 ft. per minute.

Each rotary table carries three pattern-stripping machines, an arrangement which enables three sizes of pipe to be in continuous production at the same time, if desired. Each machine incorporates four patterns arranged side by side, the design being such that hand pressure on a lever at the side of the machine causes the pattern to be withdrawn downwards from the mould; on the top is laid the actual half-moulding box.

One operator is concerned solely with slinging sand into the moulding box as it passes his station, whilst the second operator withdraws the pattern and removes the half-mould by means of an air-operated hoist carried on a runway. and deposits it on the conveyor. The third obtains an empty half-box and places

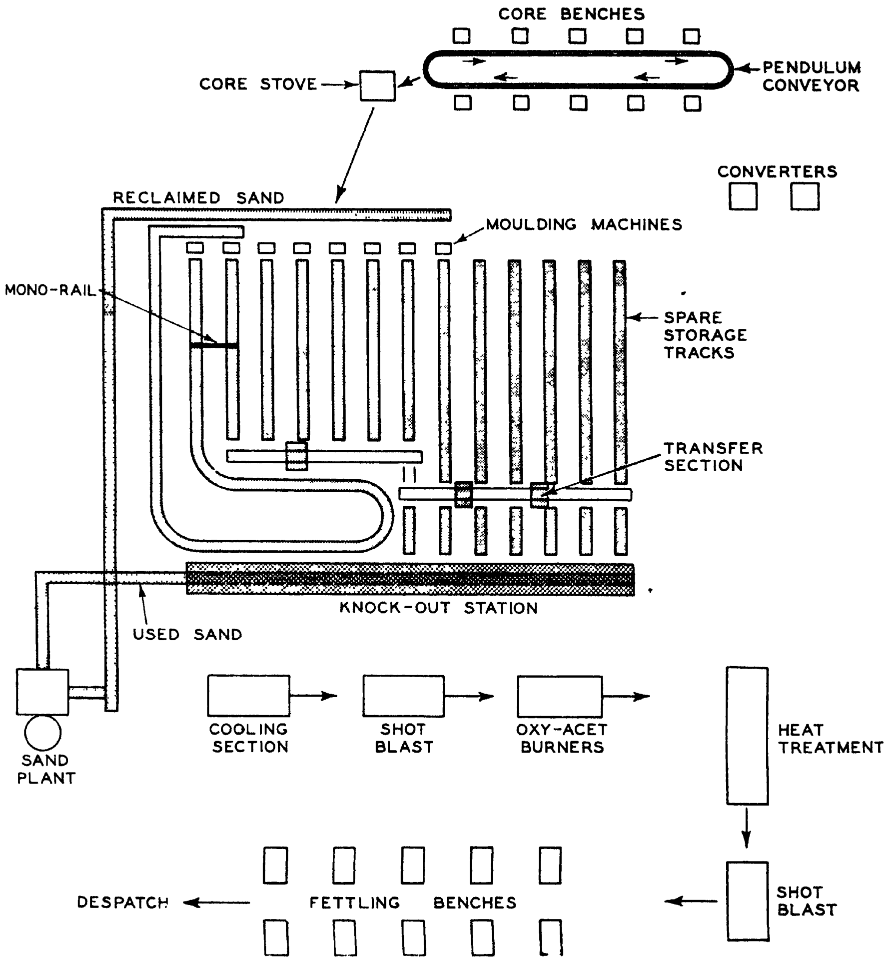


FIG. 15.—COMPLETE LAYOUT OF FOUNDRY ENGAGED WITH SHORT RUNS OF WORK

it in position over the pattern, the complete cycle occupying approximately two minutes. In a similar manner, the top half-moulds are prepared on the other pair of slingers.

The cores are made on long perforated steel arbors with the aid of four core-spinning machines situated between the two sets of sand slingers. As made, they are laid on special racks suspended from a monorail so that they can be brought over the conveyor, where they are lifted off and laid in position in the bottom moulds as they pass by. Any other small cores required to produce ears are also added as the mould moves along. As the mould passes Nos. 1 and 2

slingers the top half is added to close the mould, which then continues its journey to the pouring station.

Each mould contains four pipes connected in pairs, and is filled by four men pouring simultaneously from hand ladles containing sufficient metal for one pipe. The mould is moving continuously whilst pouring is in progress.

At the next station the steel-core arbors are withdrawn through the end of the box and placed on a special conveyor, which transports them through a tank of water. As the cooled arbors emerge, they are hooked on to an overhead pendulum conveyor and carried back to the core-making machines. The cores are suspended vertically and, for reasons of safety, the conveyor closely follows the walls of the building.

The next station is concerned with knocking out the moulds. The top half-mould is lifted first by means of an air hoist, incorporating vibrating mechanism which causes the sand to fall on to a grating below. After this, the castings are removed, and the bottom half-mould is knocked out in a similar manner. Then, by means of an overhead monorail, the empty top half-box is placed on an inclined gravity roller conveyor, which clears them from the knock-out station; at the end of the track they are picked up by hoist and placed on the mould conveyor for transportation to Nos. 3 and 4 slingers for re-use. The bottom half-boxes, knocked out at an adjacent station, are placed on separate inclined

FIG. 16.—CONTINUOUS OVAL-SHAPED MOULD CONVEYOR TRACK (*Ford Motor Co., Ltd.*)

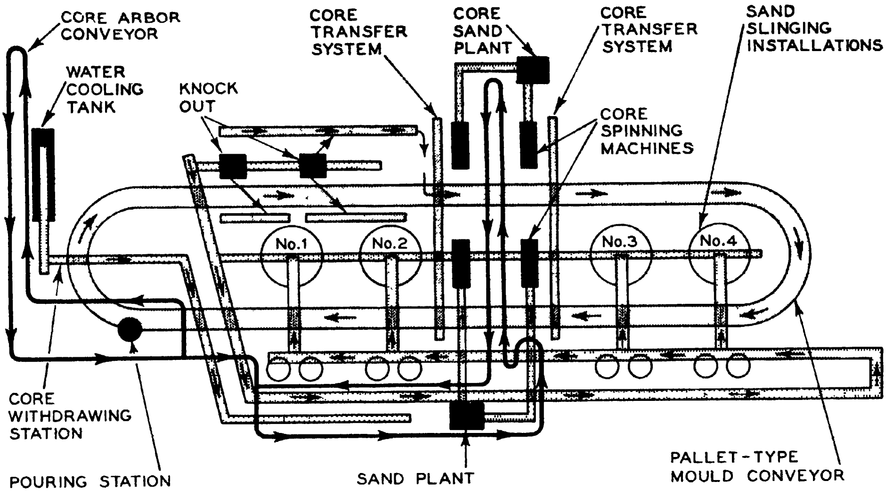


FIG. 17.—LAYOUT OF HIGH-SPEED MASS-PRODUCTION FOUNDRY PRODUCING EIGHT CASTINGS PER MINUTE

roller conveyors feeding them to Nos. 1 and 2 slingers. This completes the moulding and casting cycle.

Sand Handling

Equally efficient systems are provided for dealing with the moulding and core sands. As mentioned earlier, grid-type rotary tables are employed at each slinger station. Sand spillage falls through the grids into chutes, which direct it on to an endless belt running below the four machines and, at the end, discharges on to a cross belt leading to the sand preparation plant installed in the next shop.

Rising from below ground, the sand passes through the usual stages of reclamation. After completion of these processes the belt discharges on to a cross belt which, in turn, discharges on to another belt passing over the top of four pairs of hoppers feeding the slinging machines.

As the belt rises above floor level, it spills the used core sand on to the floor, where it is mixed by hand in the correct proportions with new sand and fed into the adjacent core-sand mill. From Fig. 17 it will be seen that this mill feeds only one pair of core-making machines. The belts carrying the sand pass under the machines, the sand then being raised by bucket elevator and discharged into a hopper at the top of each machine. These same belts and elevator also deal with the spillage sand from the core-making process. In a similar manner, the other two core-spinning machines are fed from a separate sand plant.

J. A. O.

DIE CASTING

DIE casting is the art of forming molten metal directly into an object, as nearly as possible in its final shape, without destruction of the mould. In this way it differs from the conventional sand-foundry practice, in which the mould is necessarily destroyed after each cast.

The technique in a primitive form is old. Evidence shows that many of the bronze weapons used in prehistoric times were die cast. The present standard of the art is the result of the necessity to meet an ever-increasing demand for engineering products.

The term *die casting* covers a wide field, and although generally it is understood as referring to gravity die casting or, as it is known in America, permanent-mould casting, pressure die casting, and vacuum die casting, it can with equal validity be applied to numerous other highly specialised techniques. For example, the designs on linoleum are printed frequently from type-metal blocks cast in wooden "dies," in which the impression of the design has been cut by burning. In such a "die," fifty to a hundred blocks can be cast. Another technique which can be described as die casting is the preparation of cast stereoplates used in the newspaper printing process, where type metal is cast into papier mâché moulds.

Zinc, aluminium, magnesium-based alloys, and certain of the brasses and bronzes are the most widely used alloys, but cast iron has been die cast commercially, whilst tin- and lead-based alloys have certain applications. There are innumerable compositions of die-casting alloy in daily use, each with its own particular applications. In Table I a few examples of typical alloy compositions are given, together with some indications of their melting-points, casting temperatures, solidification shrinkages, weights per cubic inch, and tensile strengths.

Advantages of Die Casting

Compared with sand castings, die castings can be produced to practically finished size. Since a die casting freezes more quickly than a sand casting of similar ruling thickness, the metal crystals in the die-cast section are smaller than in a corresponding section cast in sand. Consequently, the mechanical properties of a die casting are generally better than those of the equivalent sand casting. Die castings are free from sand inclusions and their attendant troubles, in particular those usually met with during machining operations. Obviously, a die is much more expensive to produce than a wooden pattern and corebox for a sand casting. The choice of a die-casting process to produce an article

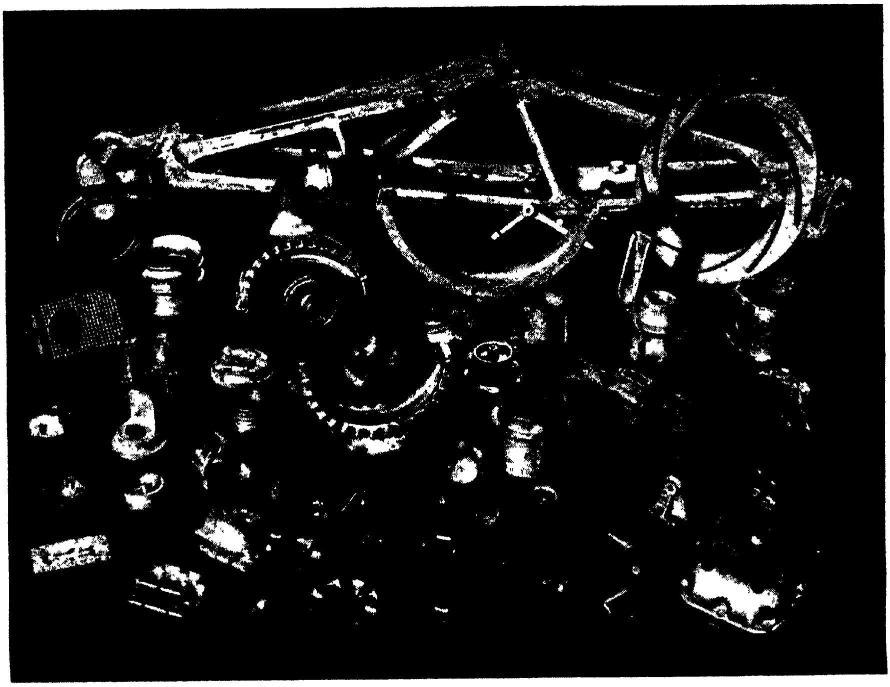


FIG. 1.—A SELECTION OF ALUMINIUM-ALLOY DIE CASTINGS

can be made only after consideration has been given to such factors as the quantity required, the probable life of the die and its cost, production speed, and finishing costs.

Fig. 1 gives some idea of the scope of die casting. In it can be seen, at the rear, a large gravity die-cast structural member (weighing over 1 cwt.) used in the construction of aircraft, and in the foreground a small pressure die-cast cable clip weighing less than 1 oz. It should be noted that even larger and smaller castings than those shown have been die cast.

GRAVITY DIE CASTING

The best way to appreciate the technique of gravity die casting is to consider the design of a die for, and the cast of, a specific simple job.

The Wire Strainer and Die Blocks

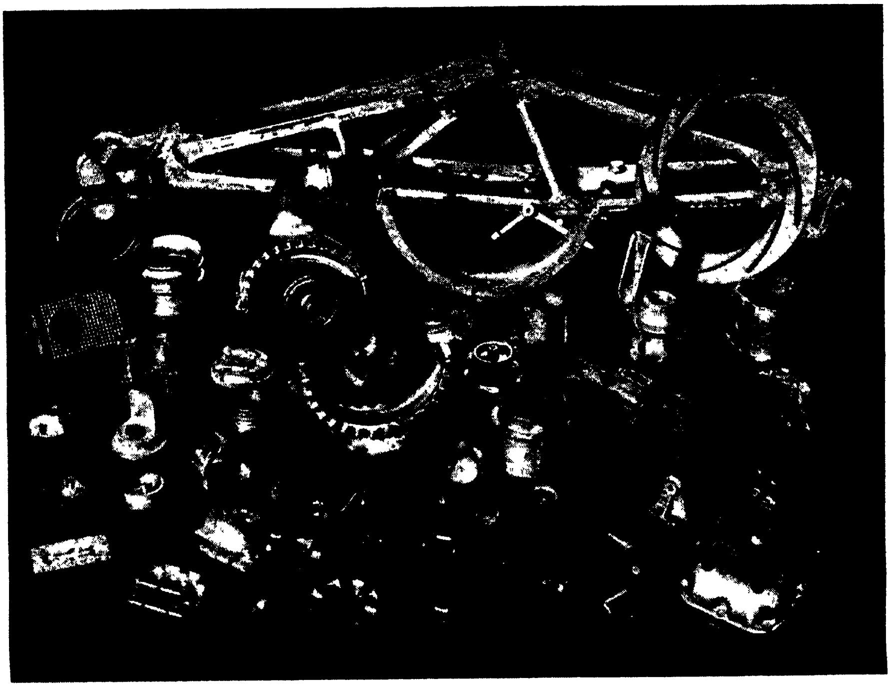
Let us consider the body of a wire strainer, shown isometrically in Fig. 2 (*a*), with the holes at *P* and *Q* to take the right- and left-hand threaded portions of the hooks, and holes at *R* and *S* to take a simple tommy bar for turning the body of the strainer round. Consideration of the job shows that a practical die to cast is that drawn in Fig. 2 (*b* and *c*). It consists of two die blocks, *A* and *B*, made in

TABLE I.—TYPICAL DIE-CASTING ALLOYS

Alloy Group	*Chemical Composition*						
	Copper	*Zinc*	*Tin*	*Aluminium*	*Lead*	*Mang.*	*Nickel*
Tin base	4–5	0·01 max.	90–92	0·01 max.	0·35 max.	—	—
	4–6	0·01	80–84	0·01	0·35	—	—
	1·5–2·5	0·01	64–66	0·01	17–19	—	—
Lead base	0·05 max.	0·01	4–6	0·01	79–81	—	—
	—	—	—	—	90	—	—
Zinc base	0·03 max.	bal.	0·001	3·9–4·3	0·003	—	—
	0·75–1·25	bal.	0·001	3·9–4·3	max.	—	—
Mag. base	0·05 max.	0·4–1·0	—	8·3–9·7	—	0·13 min.	0·03 max.
Aluminium base	0·6 max.	0·5 max.	—	bal.	—	—	0·5 max.
	0·8–2·0	—	—	bal.	—	—	0·8–1·75
Copper base	85–87	—	—	7·9	—	—	2·5–4·5
	57–59	40–42	0·5–1·50	0·10	0·75	0·25	—

Alloy Group	*Chemical Composition*						
	Silicon	*Iron*	*Antimony*	*Arsenic*	*Mag.*	*Cadmium*	*Titanium*
Tin base	—	0·08 max.	4–5	0·08 max.	—	—	—
	—	0·08	12–14	0·08	—	—	—
	—	0·08	14–16	0·08	—	—	—
Lead base	—	—	14–16	0·15	—	—	—
	—	—	10	—	—	—	—
Zinc base	—	0·075 max.			0·03–0·06	0·003 max.	—
					0·03–0·06	0·003	
Mag. base	0·5	—	—	—	bal.	—	—
Aluminium base	1·0–13·0	2·0 max.	—	—	0·10 max.	—	—
	1·5–2·8	0·8–1·4	—	—	0·05–0·30	—	0·05–0·25
Copper base	—	—	—	—	—	—	—
	—	—	—	—	—	—	—

Alloy Group	*Approx. melting-point on range ° C.*	*Approx. casting temp. ° C.*	*Contraction or solidification shrinkage, inch per inch*	*Weight per cubic inch*	*Tensile strength, tons/sq. in.*
Tin base	204	370	0·002–0·003	0·266	4·0
	204	400	0·002–0·003	0·27	4·5
	232	370	—	0·287	3·5
Lead base	237–256	300	0·002	0·37	6·1
	245–259	300	—	0·384	—
Zinc base	380	400	0·006	0·24	18·3
	380	400	0·006	0·24	21·7
Mag. base	435–604	700	0·0104	0·066	14·75
Aluminium base	565–575	700	0·0104	0·095	12·5
	635	750	0·0104	0·0985	11·0
Copper base	1,036	1,100	0·0237	0·241	34
	898	1,000	0·0232	0·261	29



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noted. The central slot is produced by two mating sections in the die, which are, in effect, fixed cores. This can be seen by the section *XX*, which shows the taper along the edge of these core pieces. This taper is necessary to enable the die blocks to part from the casting.

The casting is run through a runner *J*, which feeds into the bottom of the mould through a gate *P*; in actual practice a small witness would be left at *K*, so that the casting could be readily fettled to length. The casting is fed through a riser *L*, with a similar witness at *M*. A vent may be provided at *Q* to prevent air being entrapped there during casting.

The Casting

Assuming that the die has been completed, in order to make a casting the following procedure would be carried out:

The two die plates *A* and *B*, carefully cleaned and free from grease, would be warmed up to about 200° C., and the impressions, including a riser and runner, sprayed with a die coating.

Die coatings are suspensions of finely ground whitening and other ingredients such as mica, in either a sodium silicate water solution or in a spirit base. The most convenient way to obtain die coats is to buy them made up as proprietary brands. The depth of coat is found by experience with the die. The runner and riser should be given a heavier coat by brushing. The two halves, having been treated, are warmed up to some suitable temperature and clamped together, and the core piece, similarly coated with the die coat, is lubricated at the seat with oildag and inserted. Molten metal is poured in through *J* until it completely fills the riser *L*. In order to prevent turbulence during pouring, the die is tilted about the corner *O*, so that the metal can run gently down the side of the in-gate or runner, the die being gradually brought back to the horizontal position as the mould and riser fill. As soon as the metal is set, the side core *H* is withdrawn, the clamps unscrewed and swung clear, the die opened, and the finished casting, complete with runner and riser, lifted out.

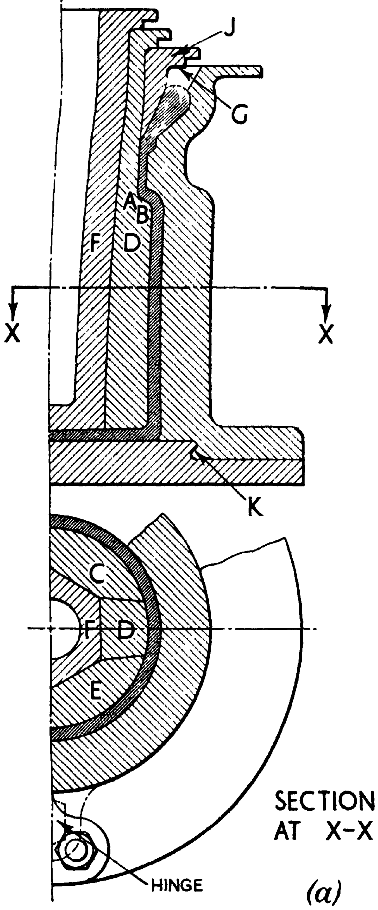
The type of clamps used on gravity dies is an important feature from the production point of view, since the time to release these clamps is often a large part of the total production time of the casting; consequently, the toggle type of clamp fastening is often preferred to the screw type.

It is most important to avoid turbulence during casting. Eddies and swirls of metal lead to entrapped oxide and voids in the casting and laps on its surface.

The optimum working temperature of the die is a matter of experience, and it is customary to cast some trial castings to ensure the correct temperature distribution throughout the die before commencing production.

Arising out of the foregoing descriptions are certain items requiring further detailed explanation.

Risers or Feeders.—The purpose of these ancillary portions of the die is to provide a head of fluid metal to compensate for any contraction in volume of the metal during its solidification in the mould proper. Risers must therefore



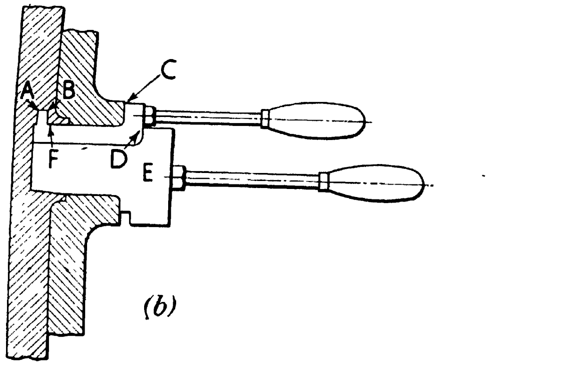


FIG. 3.—COLLAPSIBLE CORES

be of such a cross section and size as to keep molten an appreciable time longer than the actual casting being fed (see *L* in Fig. 2 (*d*)).

GATING.—In Fig. 2 (*d*) a gate *P* is shown. The function of gating is to provide a throat of a size and shape that permits the molten metal to enter the mould with the minimum disturbance.

VENTING.—In Fig. 2 (*d*) a vent *Q* is provided to prevent air being entrapped there during casting. Vents are usually made by either cutting a small V-notch, say 0·004–0·01 in. deep, along the parting face of the die from any re-entrant angle likely to trap air to the outside edge of the die, or if this is not possible, by inserting through the die wall a shouldered cylindrical plug which is a push fit in the die wall and seats on the outer face of the die. Venting is carried out by cutting a number of taper flats equally spaced round the periphery of the pin, the taper facilitating the withdrawal of flash.

TAPER OR DRAFT.—The shrinkage during solidification makes it necessary to taper all surfaces on to which the metal contracts, and in order to provide for ease of withdrawal of the solidified casting from the die form, it is necessary to arrange that the sections of all withdrawing parts be tapered. The amount of taper, depending upon the depth of the section, varies from 0·8 to 1·5 per cent. of depth of the section. No hard-and-fast rules can be given with regard to the

amount of taper to be used. From the die-caster's point of view, production is eased if a large degree of taper is permissible.

PARTING.—The faces of the two die blocks meet in the mould proper along the parting line. When considering the design of a die in which to cast a specific article, time is well spent upon positioning this parting line to its best advantage. It is often possible to reduce the number of cores necessary to produce the casting by changing the parting line. In Fig. 2, it will be seen that the central slot in the wire strainer body is made in the die form. If the plane of the parting line had been taken at right angles to the position shown, this slot would have to have been formed by possibly two moving cores, with a consequent effect upon the price of the casting.

CORING.—The core *H* shown in Fig. 2 (*d*) is a simple hand-operated core. It can be readily appreciated that in dies designed to cast more complex articles, a number of cores may be used, withdrawing in any direction, and that a variety of mechanical devices can be used to assist in their withdrawing. The axial taper or draft on cores amounts to 0·8–1·5 per cent. for their length. Naturally, the greater the taper that can be tolerated, the better. The seat of the cores should be made at least twice their diameter, and there should be a clearance of 0·004 in. between the core and its seat to form a vent.

In gravity die casting, core pieces are usually made of mild steel.

Collapsible Cores

It frequently happens that the die-caster is called upon to make an article with an undercut surface (see Fig. 3), where such a surface *AB* is shown in (*a*) internal and (*b*) external to the form of the article. Consider Fig. 3 (*a*), which shows the die necessary to cast a round case. The die mould is cast roughly to shape and hinged like a book to seat on a baseplate, being accurately positioned by a circular dovetail, which also serves to anchor the die body rigidly to the base during the casting operation.

The core-retaining ring *J* is inserted in the die body. This retaining ring is heavily vented on its mating face with the periphery of the die head. The loose pieces, *C*, *D*, *E*, etc., are inserted in their correct order and locked into position by the central core *F*. On stripping the die after casting, *F* is withdrawn and the loose pieces eased laterally into the space left vacant by the withdrawal of *F*, and then lifted clear of the die.

The shape of the loose pieces (see section at *XX*) is purposely made irregular to facilitate withdrawal and positioning. The central piece *F* is made with plain faces so as to match accurately similar faces on the loose pieces. The retaining ring is located vertically on the die wall, as shown at *G*, the core being machined to locate off the ring.

An alternative to this composite core would be a sand core made the conventional way, using sand and some binder in a corebox. The die would need to be redesigned so as to provide adequate location and support for the core. A fresh core would be needed, however, for each casting.

In the case of Fig. 3 (*b*), the external undercut, the loose piece *D* is placed in the die, its shoulder butting up to a machined seating *C* on the die wall, and the core piece *E* is inserted underneath *D*, as shown in the sketch. After casting at the correct temperature, *E* is withdrawn, *D* dropped down to clear surface *BF*, and withdrawn.

Inserts

The technique of die casting lends itself to the use of preformed inserts, such as steel studs, bearing pockets, etc., which are set in the mould frame in such a way that they are cast into the die casting during its production.

Slush Casting

This is a method of gravity die casting hollow articles such as lead soldiers, aluminium teapot spouts, and zinc-base alloy statuary, in low-melting-point alloys.

The die is constructed in two parts, *A* and *B*, hinged together like a book, and secured by a catch *C*, so designed that the faces of *A* and *B* are held firmly together (see Fig. 4). The impression of the article to be cast is cut half in *A* and half in *B*, so that on closure the two half impressions mate accurately. The die halves close on to a circular rebate machined in a false base *D*. False base *D*, which normally sits on base *G*, is capable of being turned in a vertical plane about *E* by handle *F*.

In the example, the impression to make a simple bust has been shown. To produce a casting, the die is closed, catch *C* fastened, and the requisite amount of molten metal poured into the mould so as to fill it. Partial solidification is allowed to proceed, depending upon the thickness of the article required, and then the still liquid metal emptied out of the mould by turning it about *E* over lip *H*. The mould is returned to the horizontal position, opened, and the hollow article taken out.

Generally speaking, the maximum practical thickness to which a slush cast article can be made is about $\frac{1}{8}$ in.

PRESSURE DIE CASTING

Pressure die castings are made by the solidification of molten metal in metallic dies under a pressure greater than atmospheric. This implies the use of a machine to provide the pressure during the casting process.

Pressure die castings are of excellent surface finish, and, after buffing, are ready for plating or other finishing process. They can be cast to very close dimensional tolerances. For example, a casting whose maximum dimension does not exceed 3 in. could be made in a zinc-base alloy, so that each inch of length or diameter was held to $\pm$ 0·001 in.

Die-casting machines fall into two classes, those of the gooseneck type and cold-chamber machines with the Polak design of machine as a possible sub-division of this latter family.

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(4) Ancillary mechanism usually interlocked with the die-block movement for separating the cast metal from its source and for ejecting the casting.

Such a machine is shown diagrammatically in Fig. 5.

The die block B is fixed to the machine frame through which passes the injector nozzle C, fitted so as to be capable of ready replacement. The die block A is arranged to be closed on or opened off B mechanically. Block A also carries the sprue cutter D, whilst block B carries the ejector pins E. The nozzle C is attached to the gooseneck G, which is immersed in the molten metal held in a pot P. The molten metal is maintained at level M. The pot P is heated by gas firing or other means so as to maintain the metal in it at the correct casting temperature. The gooseneck G is cast integral with a cylinder F having inlet ports H, and machined and fitted with a plunger J.

The machine is operated as follows:

Let it be assumed that a casting has just been made and removed from the machine, the plunger being at the bottom of its working stroke, shown dotted in Fig. 5.

The die blocks are closed under pressure exerted either by cams or a rack-and-pinion device, but more usually by compressed air or hydraulic pressure. The ejector pins are withdrawn, in most cases automatically by closure of the die blocks. The sprue cutter is pulled back. The plunger is raised to the top of its stroke, and molten metal flows through the ports H into the gooseneck, filling it. The plunger is depressed. During the early part of its stroke it closes the entry ports H, and isolates the metal in the gooseneck from the metal in the pot. Further movement downwards of the plunger forces the metal through the nozzle into the mould formed by the closed die blocks. The sprue cutter is operated, separating the metal in the casting from that in the injecting nozzle. The die blocks are opened and the casting ejected from the die block B by the ejector pins.

The gooseneck-type die-casting machine is limited in use by the fact that a portion of the machine is continually immersed in the molten metal. This means that the machine can be used only to cast alloys having a much lower melting-point than the material of the gooseneck, and which are not contaminated, chemically, by long contact with the gooseneck at high temperature. In an endeavour to overcome this latter defect, the gooseneck is frequently coated with whitening.

Such die-casting machines are extensively employed in the production of tin, lead, zinc, and magnesium base and, with certain reservations, some of the aluminium-base alloys.

The Cold-chamber Machine

In the cold-chamber machine, the melting furnace is separate from the machine, a ladleful of molten metal being poured into a bushing, which may be water cooled, and then transferred by means of a plunger into the die cavity. The cold-chamber machine is used to die cast certain alloys, notably the aluminium-base alloys which tend to absorb the iron of the gooseneck and

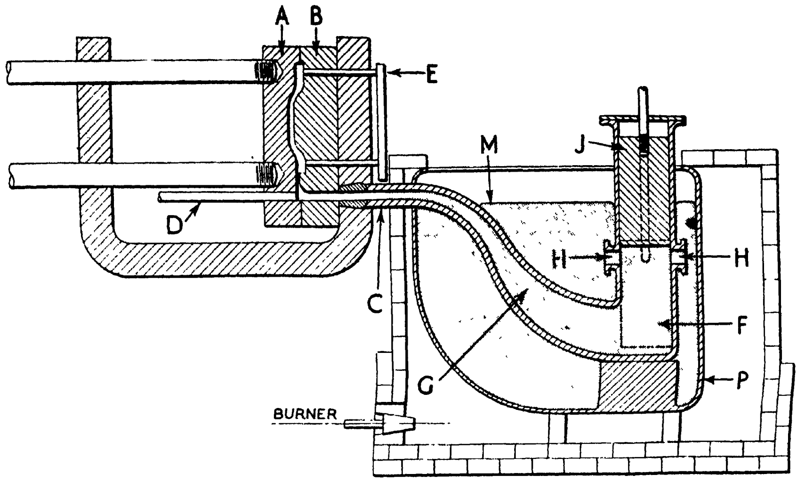

FIG. 5.—GOOSENECK DIE-CASTING MACHINE

melting-pot of the gooseneck machine. In the case of the cold-chamber machine, the melting-pot is made of plumbago and the molten metal is in contact with the bushing a very short time only.

Fig. 6 shows a typical cold-chamber machine diagrammatically. The die blocks *A* and *B* are securely fastened to die members of the machine by clamps and T-slots. As shown, the block *B* is fixed to the moving member *P*, which is equipped with the pouring bushing *C*, through which the plunger *R* can operate. The die block *B* and platen *P* are designed so that they can be moved backward to such position that the slug of metal left in the bushing after a casting has been made is ejected clear of die block *B*. The plunger is then retracted and the casting is ejected from the fixed die block *A* by means of ejector pins, which are operated either mechanically from *B* or by a separate hydraulic system.

Fig. 7 shows diagrammatically the casting process necessary to make two caps having two cored holes along the parting line of the die which, for the present purpose, we will assume cannot be cast in any other way. In Fig. 7 (*a*) the die blocks *A* and *B* are held together with a locking pressure of the order of 50 tons, the ejector *E* being in the retracted position and the plunger *R* being clear of the pouring hole in the bushing *C*. The two side cores S_1 and S_2 are in the casting position. The requisite amount of molten metal is poured into the bushing, and the plunger is moved forward to fill the die cavity (see Fig. 7 (*b*)). The side cores are withdrawn after solidification has occurred and the die block *B* moved back (see Fig. 7 (*c*)). In most designs of die the side cores would be withdrawn by a mechanism interlocked with and operated by the movement of *B*, after the plunger is retracted. The ejector *E* is operated, and the casting is pushed clear of the die cavity (see Fig. 7 (*d*)).

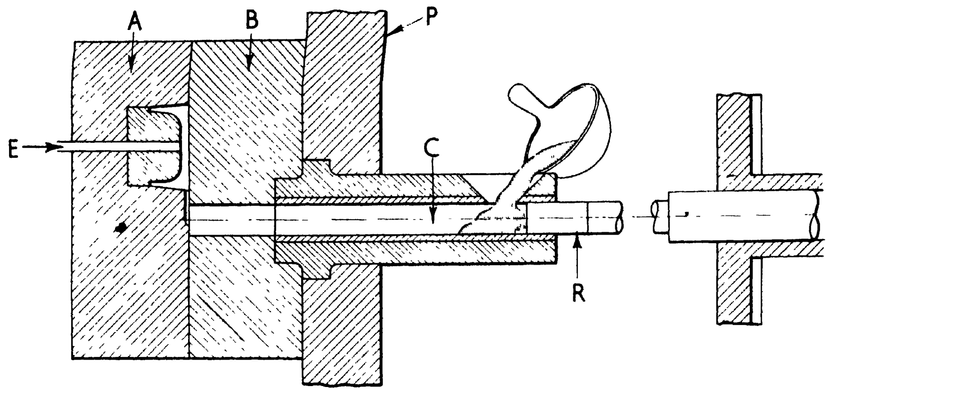

FIG. 6.—COLD-CHAMBER MACHINE

The Polak Die-casting Machine

This design of machine is specially adapted to the die casting of brass, bronze, and similar alloys, which are forced into the die in a semi-molten or plastic state. A much lower temperature is employed, therefore, than if it were necessary to handle the metal in the molten condition. Consequently, the useful life of the dies is considerably increased, although the abrasive action of the plastic metal may quickly wear away the sprue. This process is also sometimes referred to as the pressed casting process.

There are two techniques used with this machine:

(1) In which the metal is ladled into a separate compression chamber (the central-gate die process).

(2) In which the metal is ladled into a chamber provided in the top of the impression in the die (the split-gate die process).

These designs are shown diagrammatically in Figs. 8 and 9.

The Central-gate Process

A quantity of semi-molten metal in excess of that required for the casting is emptied into the compression chamber *C* on to the top of a spring-loaded plunger *S* (Fig. 8 (*a*)). The die blocks *A* and *B* are held together by a hydraulic ram, which in the largest machines of the Polak type will be capable of exerting a load of 120 tons. The ram *R* descends and pushes the charge of metal and the plunger *S* downwards, until the gate *G* is exposed; by this time the plunger *S* is seated on the bottom of the compression chamber, and further travel of the ram forces the plastic metal through the gate *G* and into the mould. When the die cavities have been filled with metal, the ram *R* is retracted. The spring-loaded plunger *S* follows this movement, shears off the sprue, and carries the surplus metal in the form of a solidified disc, *P*, clear of the die blocks to a position where it can be readily removed. The die blocks are then opened and the finished die casting pushed off block *B* by an ejector mechanism *E* operating through the block (Fig. 8 (*b*)).

The Split-gate Process

In this process the use of the spring-loaded plunger to cut the sprue and to eject the surplus metal is obviated. The die blocks are held together hydraulically, and the charge of metal emptied into the compression chamber *C*, which is integral with the die cavities (Fig. 9 (*a*)). The ram descends and forces the metal into the mould through the gate *G*. The ram is retracted and the die opened, the casting being ejected by the ejector *E* (Fig. 9 (*b*)).

DIE CASTING BY THE VACUUM PROCESS

This process is generally employed in the die casting of the higher melting-point alloys, such as aluminium bronze. In principle, the process is the reverse of the one followed in pressure die casting. The assembled die, with a gate or runner at the bottom of the die, is lowered into a pot of molten metal until the

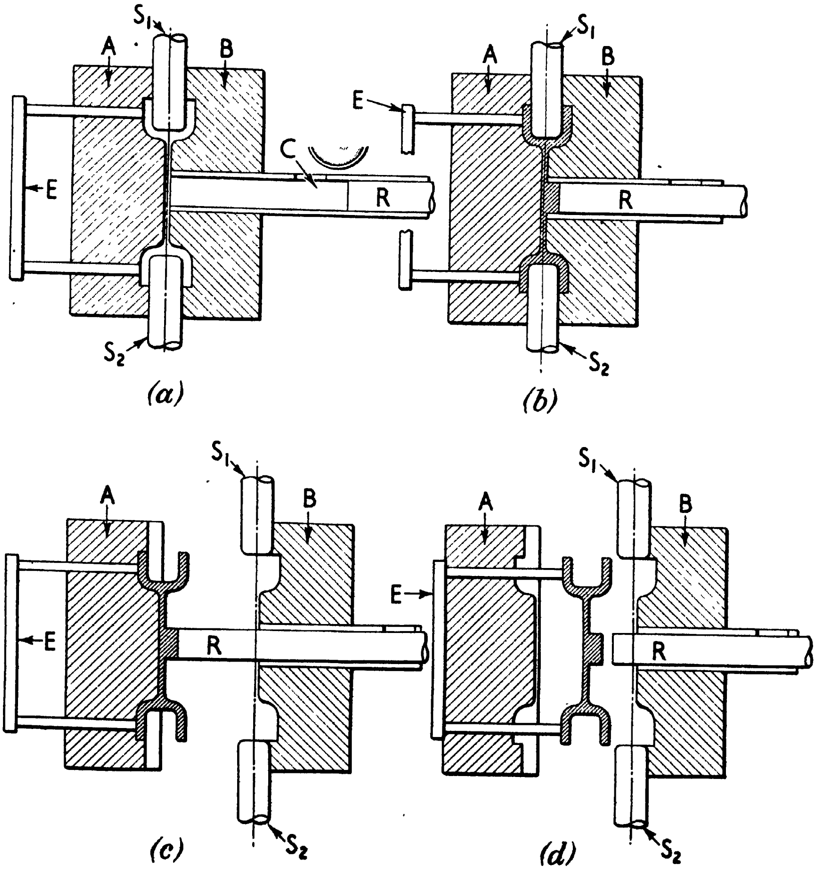

FIG. 7.—OPERATION OF COLD-CHAMBER MACHINE

gate is a few inches below the metal surface. From the upper portion of the mould a pipe connects to a vacuum system via an automatic valve, so that as the air is drawn off the die, the molten metal is sucked through the gate. As soon as the die is filled, and after solidification has taken place to some extent, the vacuum is disconnected, the die raised from the pot, swung to one side, and the casting taken out.

Bronze castings up to 30 lb. weight have been made by this process, and a dimensional tolerance of 0·005 in. per inch can be maintained.

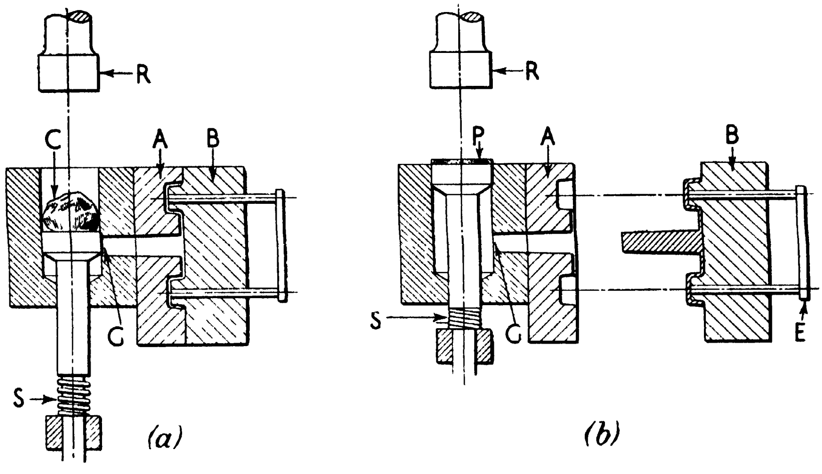

FIG. 8.—POLAK MACHINE, CENTRAL-GATE PROCESS

THE FINISHING OF DIE CASTINGS

No account of the die-casting processes would be complete without some mention of the various stages through which a die casting passes before it can become a component ready for assembly or use.

Gravity Die Castings

The runners and risers are first sawn off on band-saws, using jigs to secure and correctly offer them to the saw. In some cases, particularly with internal risers, it may be necessary to set the casting up on a milling machine. The sawn or milled surfaces, after filing by hand or by one of the types of rotary files, are finished off on a finishing machine or a sander.

Pressure Die Castings

The castings are usually processed, if the quantity warrants it, by specially designed fashing dies under a small press which removes in one operation the gate, any adhering sprue, and all the lash. An exception to this procedure are castings made by the Polak process, which in any case, because of the heavier proportions of the gate, may have to be processed by the methods referred to under gravity die castings.

Small pressure die castings are sometimes fettled by rumbling.

Dependent upon composition, alloy die castings are subject to further treatment. For example, zinc-base alloys of certain compositions are stabilised dimensionally by a heat-treatment at 100° C. for 3–6 hours, which may be followed by pickling in a chromate bath to give a corrosion-resisting surface or by a conventional electroplating process.

Magnesium-based alloys, after heat-treatment to develop the best mechanical properties possible and final polishing, are pickled before painting. The selection of the proper pickle depends largely upon the service conditions. For interior use, a chrome pickle provides a satisfactory paint base, but for severe exterior use, a pickle embodying hydrofluoric acid is necessary.

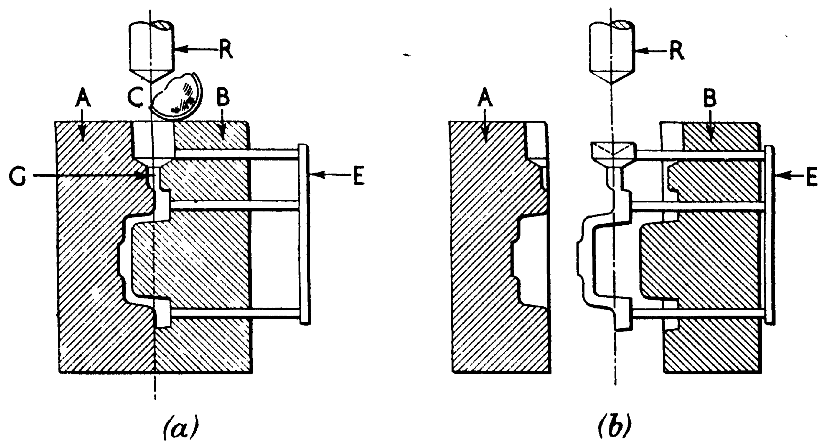

FIG. 9.—POLAK MACHINE, SPLIT-GATE PROCESS

On the other hand, aluminium-base alloy die castings can be put into service without any treatment other than an adequate heat-treatment.

MATERIALS USED IN THE CONSTRUCTION OF DIES

Gravity Dies

For gravity casting, the selection of a suitable die steel does not appear to offer much difficulty. Lead-, tin-, and the zinc-base alloys, cast iron, or a plain carbon steel untreated, have been found to last a considerable time and only to fail ultimately through mechanical wear in handling.

With the aluminium-, magnesium-, and copper-base alloys, satisfactory results are obtained with cast iron, mehanite, and steels lightly alloyed with chromium, molybdenum, or vanadium.

In order to prevent distortion of the mould during use, it is preferable to anneal the rough casting at 800–900° C. before machining. Where possible, moulds are cast to such a shape as to require the least amount of finishing.

For the gravity die casting of aluminium bronze, cast semi-steel die blocks have been successfully used.

Cores are usually made in mild steel, but for the higher melting-point alloys such as brass, etc., or collapsible multi-piece cores, low-alloy steels are sometimes used.

In one case an expensive die, from which many castings were required in aluminium bronze, was made in a heat-resisting steel, 20 per cent. nickel to 25 per cent. chromium, and gave excellent service, though the actual initial cost was high.

Pressure Dies

Cast-iron die blocks may be used for tin- and lead-base alloys and for zinc-base alloys if the form is simple and the production runs short; generally speaking, however, die blocks for pressure dies are made in alloy steels.

The properties desired in a steel are:

(1) Resistance to crazy-cracking or crocodiling of the die surface, due to the succession of thermal stresses generated by the rapid temperature changes of the surface during service.

(2) Resistance to abrasion by fast-moving molten metal.

(3) Resistance to mechanical wear by moving parts, such as ejector pins, cores, etc.

(4) An overall toughness to withstand the rough usage accompanying high production rates.

The selection of a particular steel is determined by several considerations, of which the initial cost of the steel block is the least important:

(1) The cost of the die due to its size and complexity of design and the production which may be expected from such die.

(2) The capacity of the die sinker to carry out the necessary workmanship on the die at different degrees of hardness.

(3) The facilities available for hardening and tempering the die, and the degree of risk of cracking or distortion in final treatment, which probably depends more on the intricacy and varying sections of the die than on the analysis of the steel.

Table II gives a brief summary of compositions of die steels for various alloys.

Much effort has been and is being put into the development of the best steels for each specific purpose, and although much progress has been made, finality has by no means been reached.

Cores intended for use with tin- and lead-base alloys are often made in mild steel or medium carbon steel. In the remaining cases, steels similar in composition to the die blocks are used, although much surface-hardened by the nitriding process.

It will be seen in Table II that the steels generally in use for the aluminium-base alloys fall principally into two groups, those with essentially 5 per cent. chromium and those with essentially 10 per cent. tungsten.

The experience of die users varies very greatly, and diametrically opposite opinions are held by different users of identically the same steel. This is not so surprising in view of the very many variables in conditions and practice which affect the lift of the die.

Hardness of Die Surfaces

The hardness generally suggested for the surfaces of dies seems to increase with the temperature of the metal cast: for zinc- and tin-base alloys hardness 200–255 Brinell, for the aluminium-base alloys 400–450 Brinell, and for the copper-base alloys 450–520 Brinell. The advisability for the high degree of hardness is becoming a subject of doubt among many users. A minimum hardness is no doubt necessary to resist wear in moving parts and abrasion by injected metal in dies of some designs, and it may be desired to withstand damage by careless closing of imperfectly cleaned dies, or to ensure a high degree of polish. Heat-treated high-tungsten steels have high tensile strength, not only at atmospheric temperatures, but at temperatures of 500° C. or 700° C. But this strength and its corresponding Brinell hardness may not be the characteristic necessary to resist the surface cracking due to repeated heat stresses.

Dies in nickel-chrome molybdenum steel of exceptionally low carbon content have given excellent service with both aluminium and brass. The low carbon content reduced the hardness to the order of 360–390 Brinell, which may be considered low, but it possibly also accounted for the apparent increased resistance to crazy cracking. Many such dies can be sunk in the heat-treated condition, thus avoiding the difficulties and risks of treatment of the finished dies. The amount of work to be done at this hardness, however, can be reduced by delaying treatment till the die is nearly finished.

Design Modification

When it is considered that for a particular project a casting might very well be made as a die casting, the designer is well advised to consult the diecaster as early as possible, so that if needs be the casting design can be modified to suit the diecaster. Such collaboration is well worth while from both the technical and the financial standpoint.

Experience is a most important factor in the successful exploitation of the various die-casting techniques, particularly when it is remembered that, even after a specific die has been designed and made, it more often than not will require certain minor modifications before a succession of castings can be produced commercially. Such details as die temperature, thickness of die coat—which is not necessarily uniform over the entire die surface—casting temperature of the alloy, stripping time of the die, all have to be found by trial and error.

TABLE II.—COMPOSITIONS OF DIE STEELS

C.	*Si.*	*Mn.*	*Ni.*	*Cr.*	*Mo.*	*V.*	*W.*	*Co.*
				ZINC-BASE ALLOYS				
0·20–0·50	0·25–0·45	0·50–0·80	—	—	—			
0·40–0·50	0·25–0·35	0·40–0·80	—	2·0–2·5	—			
0·35	0·25	0·65	—	1·25	—			
0·50–0·70	0·15–0·25	0·60–0·70	1·0–1·8	0·65–0·85	—			
0·5–0·7	0·15–0·25	0·6–0·7	1·6–1·8	0·80–0·85	0·25–0·30			
0·40	0·25	0·60	0·20	1·3	0·85			
				ALUMINIUM- AND MAGNESIUM-BASE ALLOYS				
0·30	0·70	0·25	—	4·5	1·4	1·4	0·90	—
0·35	1·0	0·65	—	5·25	0·6	0·15	—	—
0·40	0·90	0·40	—	5·25	0·9	0·5	—	—
0·35	0·9	0·30	—	5·25	—	—	4·5	—
0·40	1·0	0·40	—	5·5	1·1	1·0	—	—
0·25	0·40	0·30	2·16	3·17	0·5	0·75	10·0	—
0·40	0·25	0·60	—	1·3	0·85	—	—	—
0·25	0·15	0·25	2·25	2·5	—	0·5	10·0	—
0·30	0·15	0·25	—	3·0	0·55	0·4	10·0	—
0·40	0·35	0·30	—	3·0	—	—	9·0	—
0·40	1·0	0·25	—	5·0	—	—	5·0	0·50
				COPPER-BASE ALLOYS				
0·40–0·45	0·35	0·36	—	1·7–2·7	—	0·40	10·0–15·0	—
0·30	0·25	0·30	—	4·0	—	0·45	14·5	—
0·33	0·30	0·35	—	3·0–3·25	—	0·40	9·0–11·0	—
0·55	—	—	—	4·0	—	1·0	18·0	—
0·35	—	—	—	3·0–5·0	—	—	6·0	—
0·25	0·25	0·50	—	4·0	—	0·45	—	—
0·18	0·22	0·38	—	6·5	4·0	0·33	3·5	0·43
0·23	0·45	0·27	2·16	3·17	0·53	0·75	10·0	—

It is easy to appreciate that it is quite impossible in any short article to do other than outline basic principles, and for further details reference should be made to specialised publications such as:

Gravity Die-casting Technique, G. W. Lowe.

Die Casting for Engineers, New Jersey Zinc Company.

Die Casting, Herb.

Aluminium Alloys, Zeerleder, translation by Field.

The Technology of Magnesium and its Alloys, Beck, translation by F. A. Hughes & Co.

Aluminium Bronze, Copper Development Association.

W. S. W.

HAND TOOLS AND FITTING PRACTICE

NOTWITHSTANDING the increasing use of quantity production methods in engineering works, the work of the fitter is still one of the most important branches. His accurate and highly skilled work is necessary before any of the machines used in quantity production can be assembled. Many of the engineering products for which Britain is world-famous, for instance the Rolls-Royce engines, can only be manufactured with the required degree of perfection owing to the high skill of the fitters engaged in their construction.

The present section deals thoroughly with the craft of fitting. The subject is grouped under four main divisions; the first of these deals with fitters' tools and equipment and methods of using them. This introductory portion is followed by notes on the principles of lining out, including the use of measuring appliances.

Actual fitting operations, such as riveting, key fitting, fitting cotters, bolt and stud fitting, and the fitting and adjustment of bearings are covered next, and the treatment concludes with a description of limits, fits, and tolerances.

The Fitter's Bench

The primary equipment of a fitting shop consists of benches upon which are vices and a large array of tools and appliances. Some benches are fixed, while others are on wheels; the portable type saves journeys, and is useful for outdoor service and pipe fitting.

It used to be the custom for firms to make up their benches from stout timbers, but cast-iron standards are preferable because of their rigidity, endurance, and cleanliness. Several makers supply the iron parts on to which the customer puts the wood. In this case, the bench may have a set of single legs and may be ranged against a wall, or pairs of legs may be bolted together to provide for gangs of fitters along each side.

A well-kept bench is usually regarded as the mark of a good workman. He should keep his particular territory clean of all dirt or unnecessary articles, and even of tools that are not being used. As in other kinds of work, the fitter at the bench is dependent upon his tools and their condition for his efficiency. The tools should therefore be kept clean and in a place where they can be readily found or reached when they are wanted.

Vice

The most useful type of vice for the fitter is the parallel-jaw type, which grips the work equally to the extent of the depth of the jaws. A modified and improved form of this is provided with a quick-movement lever action which opens and closes the jaws. Types of vice are made that can be raised and lowered and also swivelled, so that the workman can operate on various parts of an object without taking it from the vice. For gripping objects of irregular shape, vices are constructed so that the jaws can be placed out of parallel. Small work that has to be shaped or drilled can often be held conveniently in a hand vice, an instrument combining the principle of pliers and vice.

Many useful additions are made to the vice for holding articles in positions which would be awkward or impracticable with the regular jaws. A bolt held upright in them supplies a handy means of clamping down flat components which cannot be seized edgewise. It is also possible to rig up a small table upon which thin plates or strips may be secured flat by a clamp.

The renewable jaws of a vice, being of serrated and hardened steel, damage any smooth-finished surfaces or soft materials. It is therefore advisable to hook soft clams over the jaws when anything other than rough castings or forgings has to be gripped.

A grip should always be taken across the thickest part of a piece held in the vice, and the blows should be directed so as to be absorbed into the vice body instead of being directed outwards where there is no jaw to sustain the shock. When hollow or flanged articles are held in the vice, care must be taken that pressure is given in direct line with solid sections instead of across overhanging or unsupported parts which would bend inwards.

USE OF TOOLS

In the following pages, the selection and use of the various types of basic tools, such as hammers, chisels, files, scrapers, and spanners, is discussed.

Hammers

The types of hammer most commonly used by the fitter include the three classes of the common machinist's hammer: the round peen, the straight peen, and the cross peen.

It is often necessary to strike a blow on finished work without damaging it, and when the material is iron or steel, an ordinary wooden mallet might be used; but with the softer metals the most suitable type of hammer is made of hide, compressed by hydraulic power, the shaft being inserted directly into the leather. Another type of soft hammer has a head of metal with vulcanised fibre blocks inserted.

To prevent the splintering of wooden mallets when used on metal, a form of mallet is sometimes used which consists of a hardwood handle fitted into a metal casing into which two boxwood blocks, easily renewable, are pressed. The chasing or repoussé hammer is used for sheet-metal working. For striking

a heavy blow, the lead-headed hammer which will not bounce away from the work can be used.

HANDLE.—The handle of the hammer must be a tight driving fit in the head and must be of such a shape that it feels easy in the hand. The head is held on the handle by means of wedges which spread the wood of the handle and cause it to bear against the sides of the hole in the head. This hole is commonly tapered, and when the handle is placed in it, the small end of the hole must be towards the body of the handle.

HOW TO USE.—When driving anything with a hammer, its face must be parallel with the object being driven. When held this way, it will neither mar the surface of the work nor slip, provided, of course, that it is clean. For striking heavy blows the handle should be grasped firmly, the arm raised straight from the object to be struck, and then the hammer should be brought down with a sharp, quick motion, held so that the face will be parallel with the object when the hammer strikes it.

When striking a light blow, movement of the arm should be just enough to give the required weight of blow. Very light tapping blows are generally made with a movement of the wrist which does not disturb the position of the arm. Grasping the handle up close to the head is commonly known as "choking" the hammer, and is dangerous, because the hand has insufficient control.

PRECAUTIONS.—The hammer must be kept tight on the handle and the face must be kept smooth and clean. The handle must not be used as a pry, nor for any sort of scraping that would roughen it.

The hand should always be free of grease or dirt when using the hammer, and both the face of the hammer and the tool being used must be kept clean. It is always dangerous to use a hammer that is not in good condition, with a face that is worn and battered, for instance, or with a head loose on the handle.

Chisels

The cold chisel and the file are valuable tools for all sorts of reduction, alteration, and mutual fitting of parts. To some extent they have been displaced through the greater accuracy now practised in the machine shop and by the adoption of portable tools, but in general work and repairs they are still constantly employed. Chisels in common use are: (1) flat, for surfacing and cutting off; (2) cape or cross-cut; (3) diamond, for roughing and grooving; (4) cow-mouth, for roughing and working in some curved spots, and (5) round-nose and oil-groove styles, for cutting grooves, the oil-groove around the curve of a bush or brass. Several types of chisel are illustrated on Fig. 1.

HOW TO USE.—The chisel should be held in one hand, while the hammer, held in the other, strikes a sharp, quick blow on its head. In the case of the flat chisel, the angle at which the chisel is held is determined by the angle at which the cutting edge is ground (Fig. 2). The lower face of the cutting edge acts as a guide while the wedging action of the metal tends to hold the chisel on a straight line. The angle has to be modified during progress across a face, according to how the edge is penetrating. It is necessary to watch the point of the chisel and

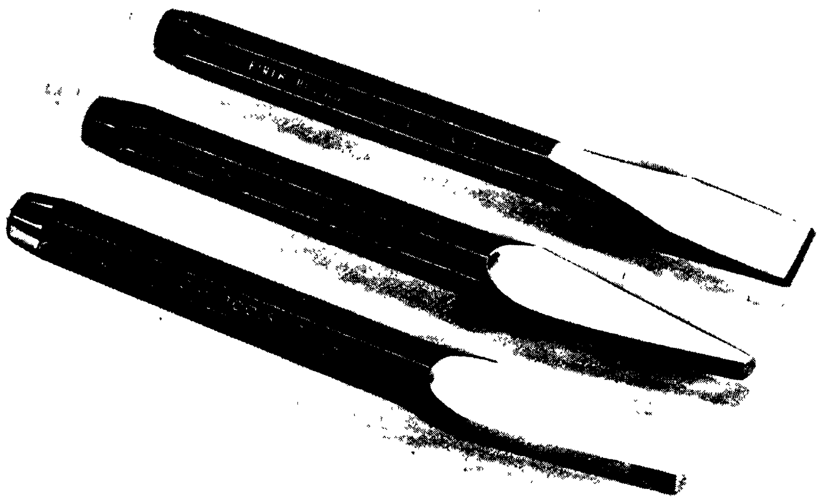

FIG. 1.—EXAMPLES OF CHISELS
(*Top*) Flat. (*Centre*) Round nose. (*Bottom*) Square-nose or key-seating chisel.
(*Firth Brown Tools, Ltd.*)

not the head, in order to keep the chisel in the proper position for cutting.

When chipping steel, the point of the chisel should be lubricated with machine oil. The edges of metal, particularly in crystalline kinds, are liable to break out if the chisel moves towards them, so that the movement should always be inward or diagonally. In chipping all cast metals, the edges of the area to be chipped should always be filed off to an angle of about 45° down to the depth of cut.

REDUCING A SURFACE.—Apart from using a pneumatic chisel, the quickest method of reducing a surface is to use a cross-cut, diamond, or round-nose chisel to plough grooves. These can be crossed at right angles by other grooves,

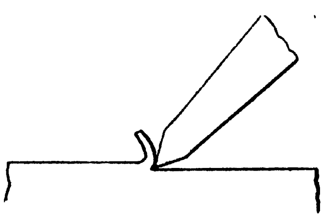

FIG. 2.—AVERAGE ANGLE OF CHIPPING CHISELS

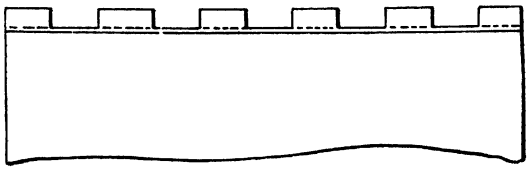

FIG. 3.—RAPID METHOD OF REDUCTION BY USE OF NARROW CHISEL

and all the upstanding blocks of metal can be removed by the flat chisel, ready for filing. If a particular depth is required, lines should be scribed round the edges, or on large areas a straightedge might be tied across in the roughing channels, to prevent risk of going too deep (Fig. 3).

PRECAUTIONS.—The head of the chisel must be kept free from oil or grease, and the hand should also be kept clean. When the head of the chisel becomes ragged, it should be ground until it is even and round. If the edge is bevelled slightly, the chisel head will have a much longer life.

Files

Files are graded into rough, bastard, second-cut, smooth and dead smooth, and also into many types, some of which are illustrated in Figs. 4, 5, and 6.

One of the most common on the fitter's bench will be the "Mill" file, which is usually rough or bastard, and is used for all rough work or fitting in its preliminary stages. For finishing, the hand file is used, which ranges from rough to dead smooth. The half-round file is also used for rough work and irregularly shaped jobs.

The square and round files are mainly used for producing or enlarging holes, and round files are also used in finishing radiused corners. The wedge-shaped knife file is used for cleaning up the teeth of gearwheels and entering slots for which other files are unsuitable. Ward files are also made for entering narrow places, and are used for making wards in both keys and locks.

Riffler files are shaped to meet special requirements; they are used, for instance, to clean round the valve guides and port walls of car engines, as shown in Fig. 7. Three-square and saw-tooth files are the tools of the saw-sharpener, and are also useful for shaping holes less than a right-angle. Block files are those without handles, mostly of square section, and are used in restricted places. The dreadnought file has curved non-clogging teeth and removes metal rapidly. It is excellent for aluminium, solder, Hoyt metal, copper, and brass, but is not recommended for tough steels.

HOW TO USE.—The file cuts only one way, that is, forward, and should not be scraped over the work on the return stroke. The fitter should stand with the left foot advanced some 20 in., with the file handle in the palm of the right hand. The handle should be pushed well on to the tang of the file to assure being

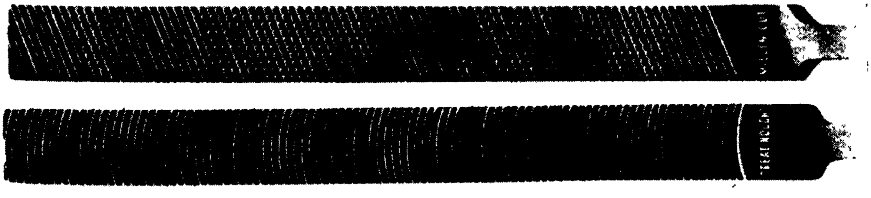

FIG. 4.—MILLENICUT AND DREADNOUGHT FILES. (*Firth Brown Tools, Ltd.*)

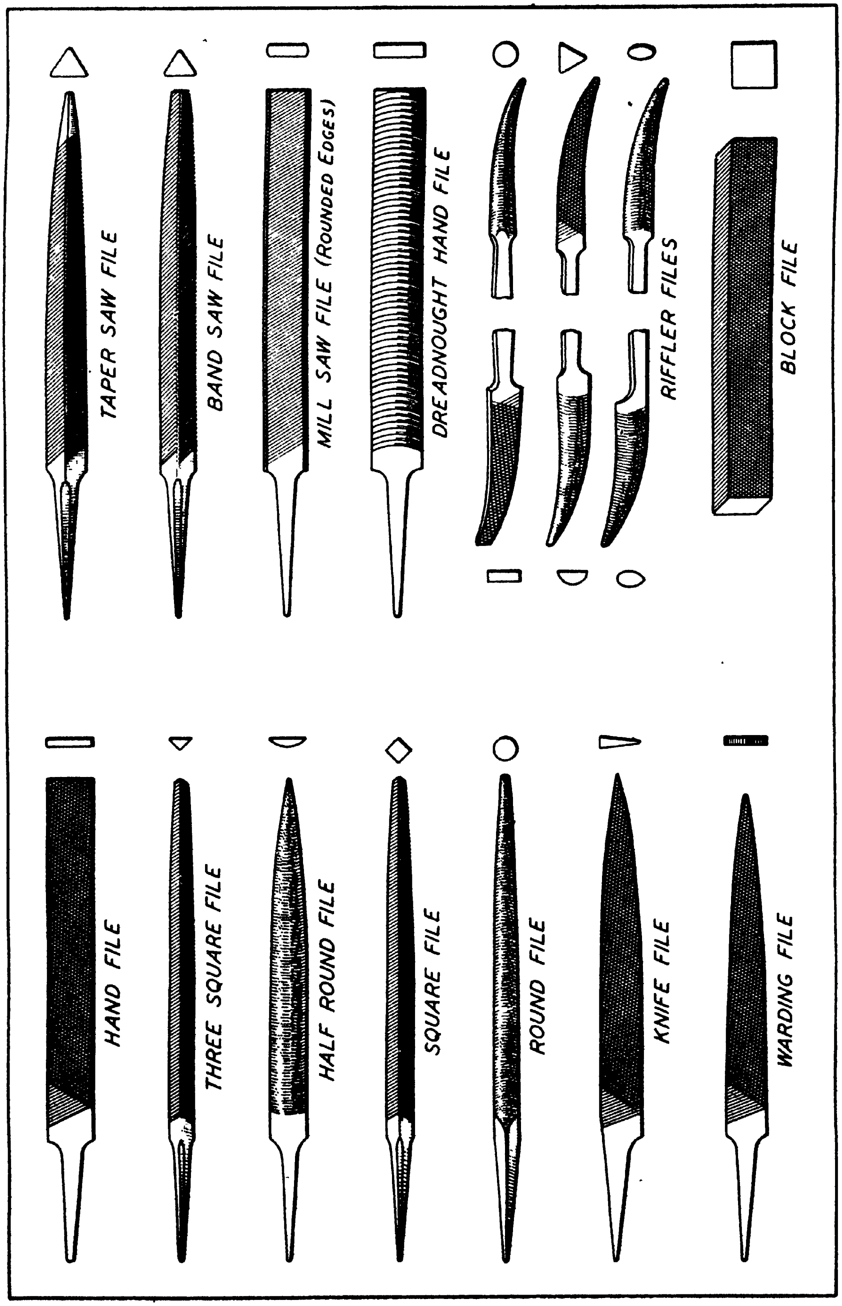

Fig. 5.—Types of file in common use

and all the upstanding blocks of metal can be removed by the flat chisel, ready for filing. If a particular depth is required, lines should be scribed round the edges, or on large areas a straightedge might be tied across in the roughing channels, to prevent risk of going too deep (Fig. 3).

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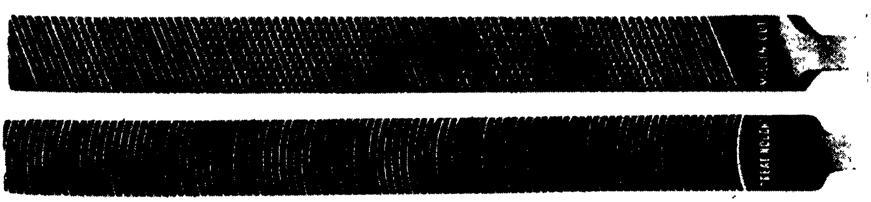


FIG. 4.—MILLENICUT AND DREADNOUGHT FILES. (*Firth Brown Tools, Ltd.*)

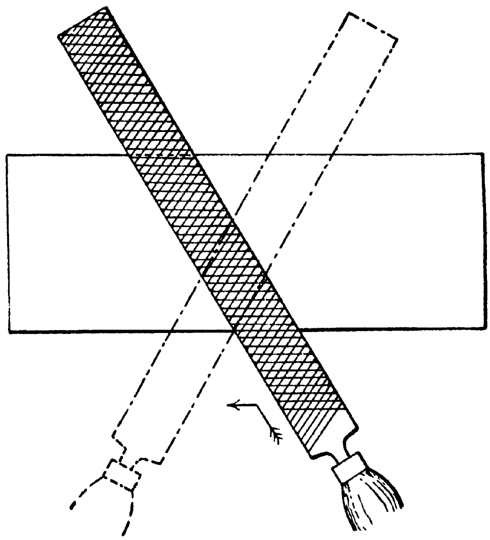


FIG. 8.—METHOD OF ROUGH FILING

To make surfaces that must be flat and true, draw filing is generally used. The file is held in both hands and laid at right angles across the work, and rubbed back and forth (Fig. 9).

To file a round surface, the file is held with the handle lifted at the beginning of the stroke and lowered as it progresses; the file is raised on the return stroke, and must be laid on the work again with a smooth, easy motion (Fig. 10).

Square holes are produced (unless machined) by square files, which clean out a drilled hole to the required size, and the hole is finished off with a square drift.

FORMING SHARP SHOULDERS.—The hand file in all grades is flat and with one edge uncut. This "safe edge" deters the file from creeping along the work when forming shoulders, and enables the operator to form sharp corners on the work with safety. In producing all shouldered work, the start should not be made right up to the scribed line, but about $\frac{1}{16}$ in. on the side to be filed. As the shoulder is being formed by the file and corrected by the square or straight-edge, the file is allowed to creep farther towards the line. When the shoulder is near its correct length and depth, a smooth file should be used. The file is then turned over to obtain a clean corner.

CARE OF FILE.—New files should only be used on the softer metals such as brass and copper; they can be used on steel and iron when dulled. To prevent clogging, a stick of chalk can be rubbed along both sides of the file before use,

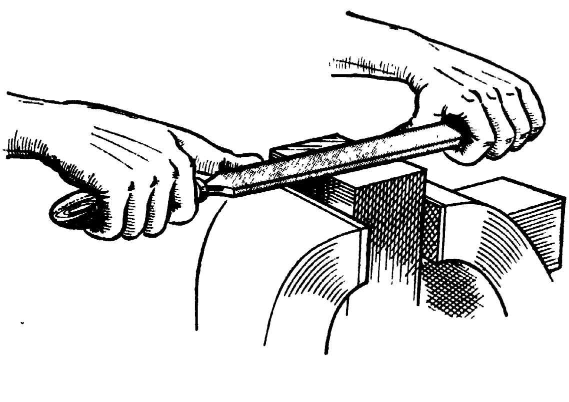


FIG. 9.—DRAW FILING

A perfectly straight file should be selected for this operation.

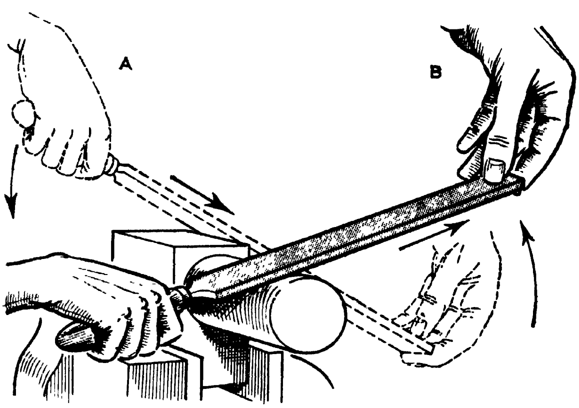


FIG. 10.—FILING ROUND SURFACES

The correct way to file round surfaces. This is by far the easiest method, and it also produces a surface that is nearer round.

or it can be painted with a very thin oil. Smooth files can be cleaned with "file carding" or by rubbing the edge of end-grained wood across the face of the file (see Fig. 11).

Filing is usually carried out dry, but with aluminium paraffin should be used to help clear the teeth. Finally, files should be kept apart and never thrown together indiscriminately, as this destroys their teeth edges.

Scrapers

Scrapers are used for finishing previously machined surfaces which must be true. Castings frequently change shape after having been machined, and often

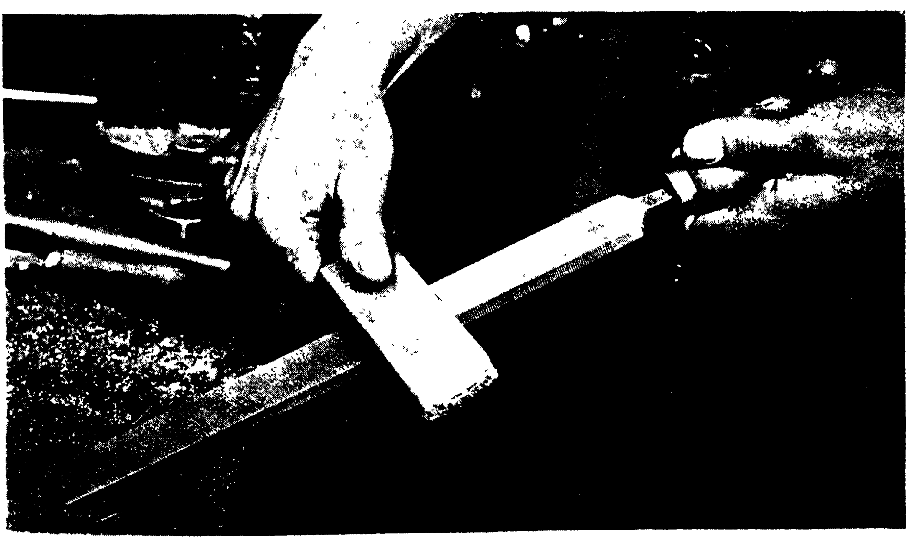


FIG. 11.—CLEANING A CHOKED FILE WITH FILE CARDING

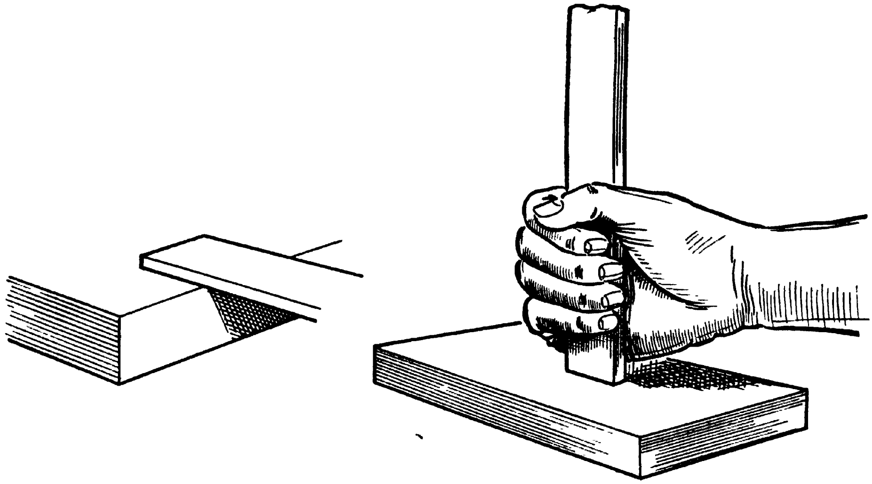


FIG. 12.—STONING A SCRAPER

the variation in the texture of the metal, together with the spring in the machine, leaves an uneven surface which must be corrected by scraping. It has also been found that large Babbitted bearings give better service when scraped.

There are a number of different forms and sizes of scraper, each being made to suit some particular job. They must be kept sharp at all times or they will not leave true surfaces and will be cumbersome to use. Sharpening is usually done on an oilstone after the cutting edge of the scraper has been ground on an emery wheel. This stoning, illustrated in Fig. 12, is necessary to remove the wire edge left by the emery wheel and also to give a finer edge.

HOW TO USE.—The straight scraper should be held as shown in Fig. 13, a slight amount of pressure being used to hold it against the work. The amount of this pressure is determined by the hardness of the metal.

When scraping a surface in which there are holes, the scraper should not be allowed to cross a hole, but should follow its circumference. When scraping on the edge of a piece, it is always best to work either towards the edge or at an angle with it but not parallel to it (see Fig. 14).

This scraper is made for use on Babbitt's metal, and is therefore ground differently from those used on iron or other metals. It has a cutting edge of about 75°. Very little pressure is required. If too much is applied, the tool will chatter and leave a rough uneven surface. A very small amount of metal should be removed at each stroke. When scraping a bearing, the direction of the stroke must always be crosswise and not lengthwise of the bearing.

Hacksaws

Hacksaws are made in different shapes and sizes, depending upon the purpose for which they are to be used, and the size is generally given as the largest blade which the frame will take. The blade should be placed in the frame

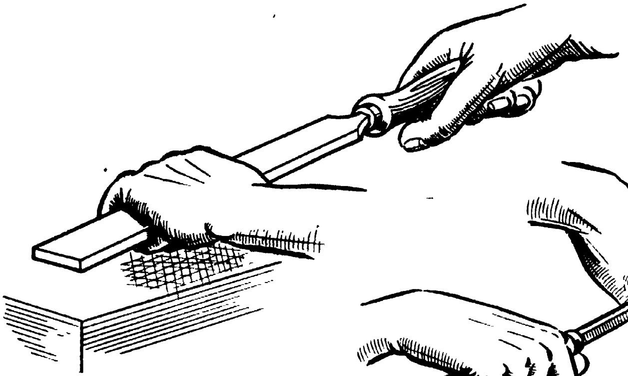


FIG. 13.—METHOD OF USING THE STRAIGHT SCRAPER   FIG. 14.—RELIEVING A BEARING

so that the teeth point towards the front end, and should be mounted securely in place over the bits, after which the adjusting screw should be pulled up tight to take out all the spring of the blade.

USE.—Like the file, the hacksaw cuts only on the forward stroke, and should therefore be lifted from the work on the return stroke. This lifting should be very slight, just enough to clear the saw from the bottom of the cut. When taking a deep cut in steel, a few drops of oil rubbed on the side of the blade will reduce friction and make the saw cut more freely, but it is generally not advisable to oil the teeth of the saw.

BREAKING.—Breaking is usually caused either by the operator bearing down too heavily on the blade, or twisting the blade by not pushing the saw straight. Work that is held in a vice for sawing must be gripped tightly so that it cannot slip, as this will sometimes cause breaking. The place where the cut is to be made should be located close to the vice jaws in order to get the greatest support possible.

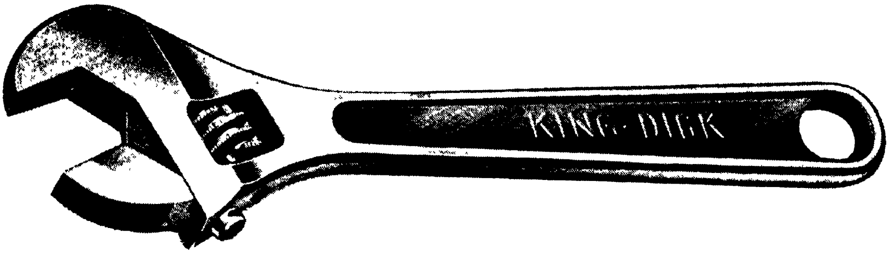
Spanners

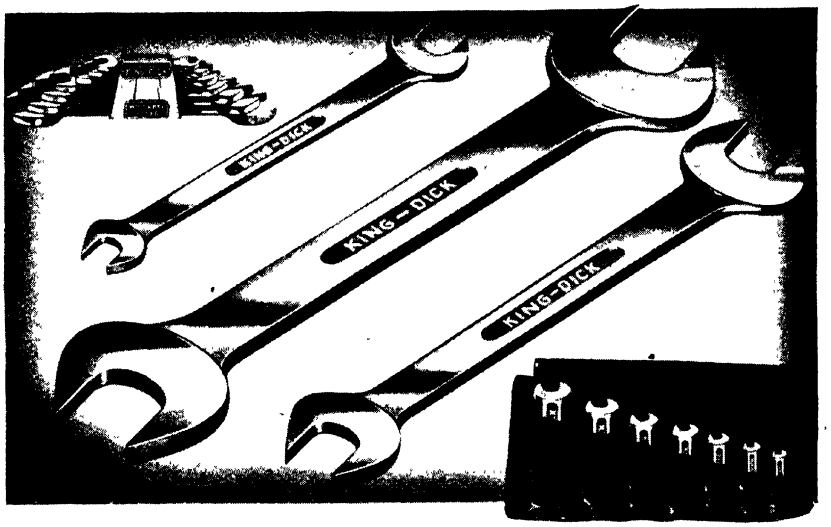
The amount of force that can safely be applied to a bolt depends upon the type of material from which the bolt is made and the length of spanner used.

It is important that the spanner should fit the nut exactly. Valuable time may be saved by an intelligent inspection of the job and a proper selection of tools. A poor fit will injure both the spanner and the nut, especially if the latter happens to be of a hexagonal shape.

The open-end spanner must fit the nut, and it must also be pulled in a direction that will tend to hold the spanner on the nut. If the arm is held so that the pull is away from the nut, the spanner is liable to slip off. The pull should always be at right angles to the body of the spanner.

Various types of spanner are illustrated in Fig. 15.





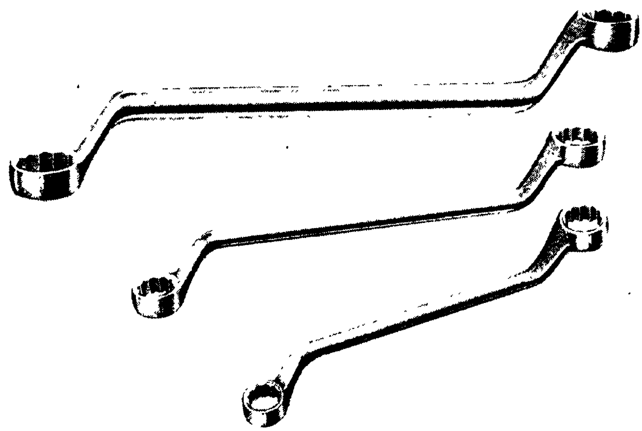


FIG. 15.—VARIOUS TYPES OF SPANNER
(*Abingdon King-Dick, Ltd.*)

SETTING UP A NUT.—When a nut is being tightened, it should be pulled up until the spanner has a firm, solid "feel." When this point is reached, the spanner should be given a sharp jerk. This will set the nut up to its final position, and will not twist off the bolt, provided, of course, that the spanner is not pulled too hard. There is a certain "feel" when tightening a nut, and it is this "feel" which tells the experienced workman that the nut is pulled up tight.

PRELOADED SPANNERS.—In special cases, where the tension of the nut has to be very accurately gauged, preloaded spanners are used. These are set to a certain tension, and when this is reached the spanner slips, thus preventing overtightening of the nut.

Surface Plate

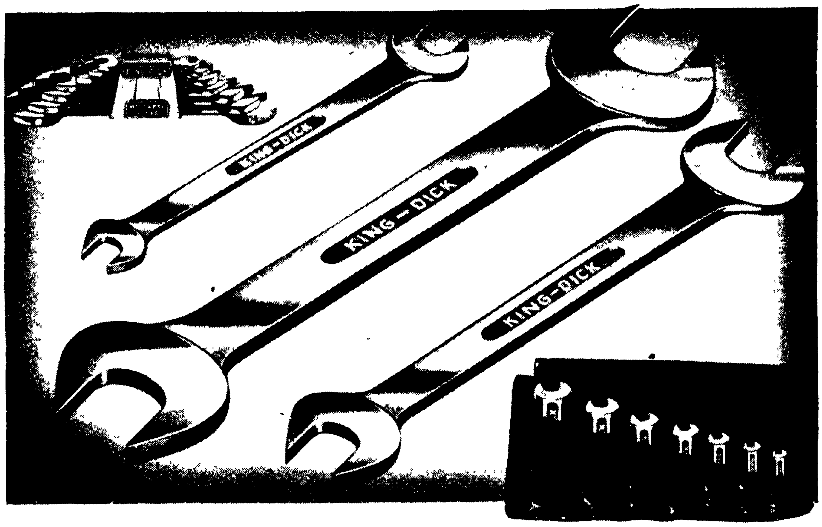
Surface plates are used, in addition to lining-out applications, with scrapers for the purpose of showing when a surface is flat and true. The plate should be level and set firmly in place so that there is no rock or shake. The surface of the the plate should be cleaned off with alcohol, for it is absolutely necessary that the plate be free of dirt or dust, or it will be marred and eventually ground out of shape by the rubbing action of the work. After it has been cleaned, a thin coating of Prussian blue should be spread over the entire surface of the plate.

SCRAPING SMALL WORK.—The surface to be scraped should be wiped clean. It is then placed on the plate and moved back and forth, or with a circular motion; only a few strokes are necessary. Then the piece is lifted carefully from the plate, without any dragging motion, and the blue spots on its surface are removed with a scraper. Each spot should be carefully and evenly scraped, only a small amount of metal being removed. The piece should then be wiped clean and placed on the surface plate again, and these operations should be repeated until the blue spots show that the surface is true and smooth. The finished surface should show a number of small spots close together and fairly evenly distributed over the entire surface.

Reamer

When reaming a straight hole by hand, it is usual to ream the hole first with a machine reamer about 0·005 in. undersize. This is followed up with a hand reamer, which is really only a circular scraper, the blades of which scrape a small amount of metal from the sides of the hole, thus bringing it to size and leaving it approximately round. All straight reamers are tapered slightly at the end, to enable them to start in the hole.

METHOD OF REAMING.—The end of the reamer should be placed in the hole and a wrench placed on its head. The reamer must then be set square with the work. One hand should be placed on the head of the reamer, over the wrench, and the reamer turned to the right (never to the left) with the other. After the reamer has been turned slightly, it should be observed again to make sure that it is started straight. The turning operation should be continued until the reamer has been put all the way through the hole, if possible. When reaming



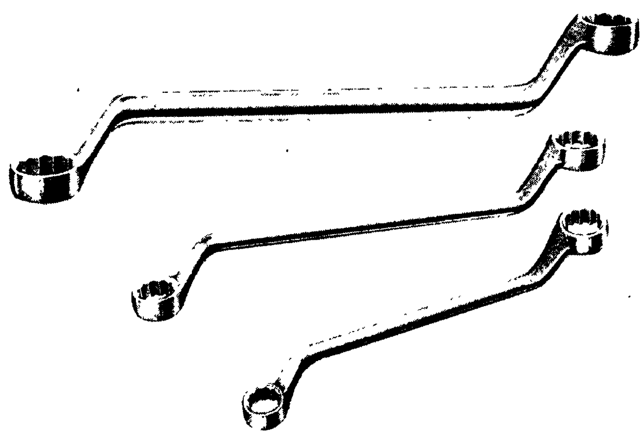
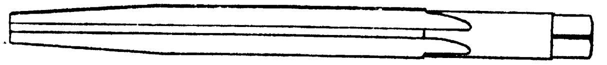


FIG. 15.—VARIOUS TYPES OF SPANNER
(*Abingdon King-Dick, Ltd.*)

G. 17.—BRIDGE REAMER FOR HEAVY WORK



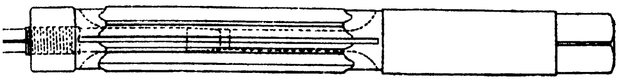


FIG. 18.—ADJUSTABLE REAMER
This type has a limited amount of expansion, obtained by screwing in the taper plug.

and then twisted with the wrench to turn the broken piece out. If heating is not feasible, a possibility is to smash the tap to pieces with a small chisel. Extractors are sold with prongs to be slid down into the flutes, to gain a grip like fingers and enable the fragment to be rotated.

SCREWING.—Good dies should not be applied to black rod, or scaly material, as the cutting edges deteriorate rapidly. Practice divides between employment of adjustable die-stocks and those of round, solid pattern. Two dies fit in ordinary stocks, to be fed together by screw according to the needs of fitting. There are three dies in the Whitworth guide stock, two being adjusted by a wedge bolt, with nut figured for noting the size obtained. The method of cutting the dies guarantees their producing a thread of correct pitch.

CIRCULAR DIES.—These are fast cutting, and ensure correct size at one

FIG. 19.—SELECTION OF THREADING TOOLS
Including taps, dies, and chasers. (*Firth Brown Tools, Ltd.*)

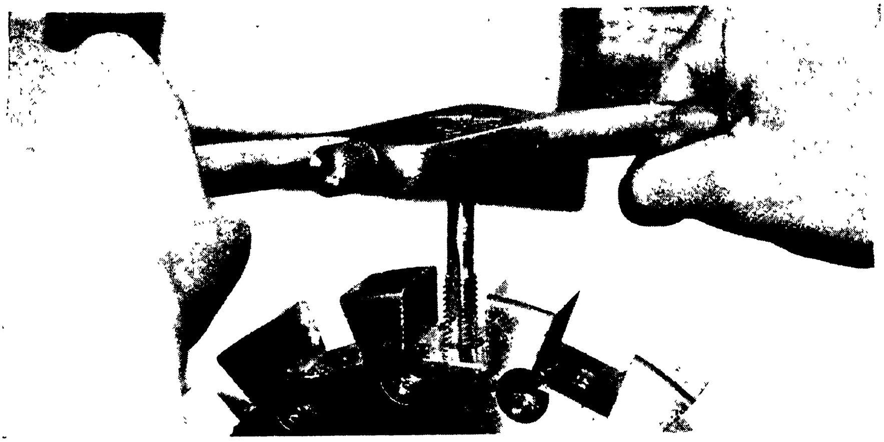


FIG. 20.—CUTTING A FEMALE THREAD WITH A TAP

going down. Numerous methods exist for adjustment of size for any particular batch of components: the die is either split through at one side and expanded and contracted by screws in the holder or stock, or made in halves. Fig. 23 shows this arrangement. A guide, not seen, lies below, and embraces the rod so that accurate control is obtained, preventing the dies from slipping crosswise and cutting a "drunken" thread. To increase cutting diameter, locknut *A* is loosened, screws *BB* slackened, handle *C* turned forward, and *A* and *BB* finally tightened.

MEASUREMENTS

In order that the close limits of accuracy required by modern fitting practice can be attained, it is necessary to use precision measuring instruments capable of reading to within 0·001 in. The micrometer or vernier callipers are ideal for this purpose.

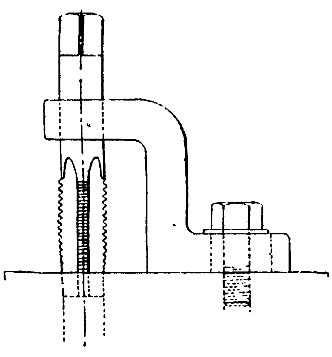
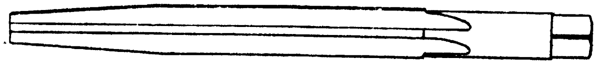


FIG. 21.—TAPER TAP AND TAP GUIDE

A tap guide is employed where perfect alignment is essential.

Micrometer

Fig. 24 shows the essential parts of a modern micrometer, with ratchet stop. The sleeve of the micrometer is graduated in fortieths of an inch. Each of the larger divisions represents $\frac{1}{10}$ in., and these are each subdivided into four. One complete turn of the micrometer thimble will advance it $\frac{1}{40}$ in. The graduations on the sleeve and thimble are shown in Fig. 25, with the scale unwrapped and laid out flat on the right. There are twenty-five divisions, and as the thimble must make a complete turn to move for-



G. 17.—BRIDGE REAMER FOR HEAVY WORK

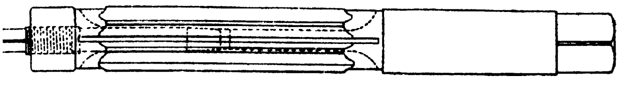


FIG. 18.—ADJUSTABLE REAMER
This type has a limited amount of expansion, obtained by screwing in the taper plug.

and then twisted with the wrench to turn the broken piece out. If heating is not feasible, a possibility is to smash the tap to pieces with a small chisel. Extractors are sold with prongs to be slid down into the flutes, to gain a grip like fingers and enable the fragment to be rotated.

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CIRCULAR DIES.—These are fast cutting, and ensure correct size at one

FIG. 19.—SELECTION OF THREADING TOOLS
Including taps, dies, and chasers. (*Firth Brown Tools, Ltd.*)

Special Types of Micrometer

The standard micrometer is only suitable for accurate measurement of the diameter of shafts or the thickness of plates, but there are several special types which can be used as micrometer gauges and for internal measurements. One type of micrometer (Fig. 28) consists of a measuring head with an extension rod or spindle. By using different extension rods, the measuring range can be varied. Fig. 29 shows a type of bench micrometer, suitable for gauging the thickness of machined flanges. The radial micrometer has three points and measures internal diameters accurately. The micrometer depth gauge is useful for measuring grooves, holes, or cavities.

Vernier Calliper

Fig. 30 shows a typical vernier calliper for reading to an accuracy of $\frac{1}{10000}$ in., with one fixed and one sliding jaw. To use the calliper, the knurled fixing screws are first loosened and the clamp and sliding head are adjusted approximately in position. The clamp member is then securely fixed in position by tightening up the fixing screw. Fine adjustment of the sliding head can then be made by using the knurled knot which can be seen at the base of the clamp

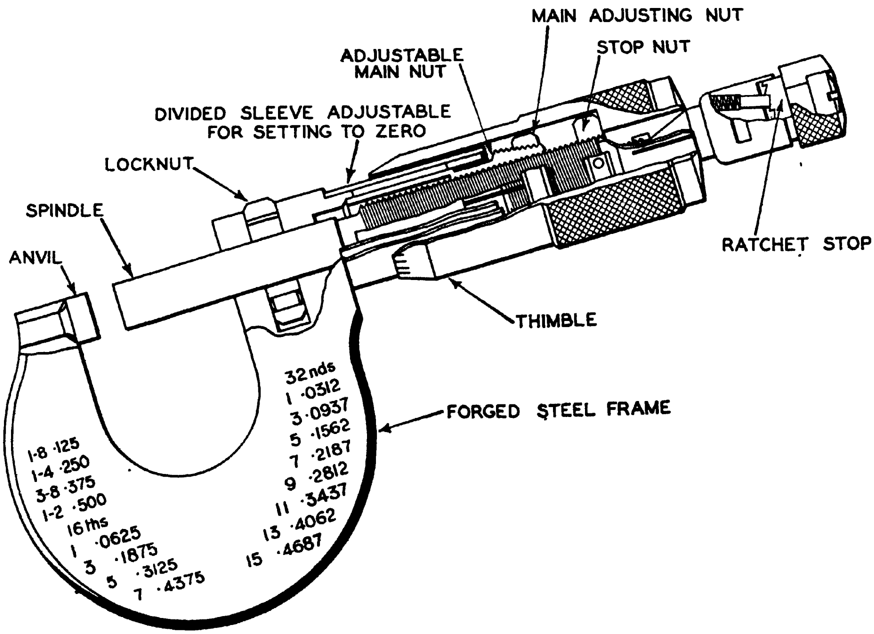


FIG. 24.—MICROMETER WITH RATCHET THUMBSCREW

Final adjustment should be made by lining the small knurled thumbscrew which is provided with a ratchet mechanism. This ensures that the spindle is always brought up against the work with the same pressure.

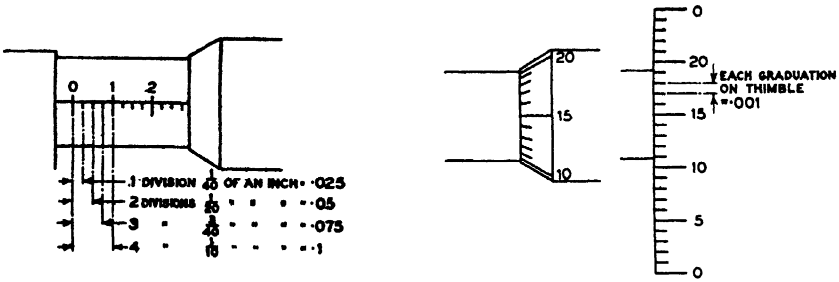


FIG. 25.—SLEEVE AND THIMBLE GRADUATIONS FOR AN ENGLISH STANDARD MICROMETER

Vernier callipers are graduated in English or metric systems. Measurement involves the use of two scales, one of which slides past the other. In Fig. 31 each of the small divisions on the upper scale represents $\frac{1}{10}$ in., and each division on the lower or vernier calliper $\frac{9}{100}$ in. Hence, if the lower scale is moved slightly to the right to bring the first division of each scale together, it must have moved $\frac{1}{10}$ minus $\frac{9}{100} = 0{\cdot}01$ in. This is the principle upon which all vernier scales are constructed.

FIG. 26.—MICROMETER IN USE

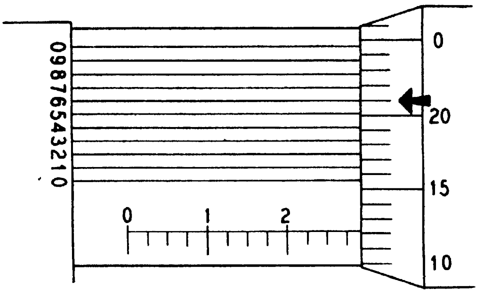


FIG. 27.—A TYPICAL VERNIER MICROMETER READING

LINING OUT

A preliminary treatment of castings and forgings is that of marking out or lining out. In a large works this is all done by a specialist, but in a small shop it may come within the scope of the fitting department, and some modified degree of lining out will often have to be done during fitting and erecting.

When objects are repeated in moderate and large numbers, templates, laid on and scribed from, assist in some of the lining out, and, if necessary, marking out can be dispensed with altogether, jigs and fixtures being used for location and to guide tools. On large castings and forgings, main distances may be dealt with by the lining-out department, and minor parts machined with the assistance of jigs.

Primary Principles

Lining out must be done in order to show the machinists how much material to remove, and exactly in what directions. It is not merely necessary to mark out the centres for turning, boring and drilling, and faces for planing, shaping, etc., but very careful consideration must be given to faults and inaccuracies in the rough castings and forgings. An approximate average must first be arrived at, deciding where sound metal is most imperative, where flanges must be kept thick and strong, and whether more or less variation may be permitted in certain dimensions.

Procedure

Appliances and tools for lining out commence with a level plate to provide an accurate reference for measurement. This may be a small bench plate, a large plate on legs, a larger T-slotted floorplate, or sometimes any bed or table of a fixed-type machine, on which the article is bolted ready for machining.

There are two procedures involved in lining out: testing and marking. In

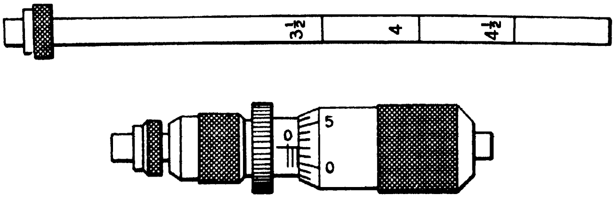


FIG. 28.—INSIDE MICROMETER

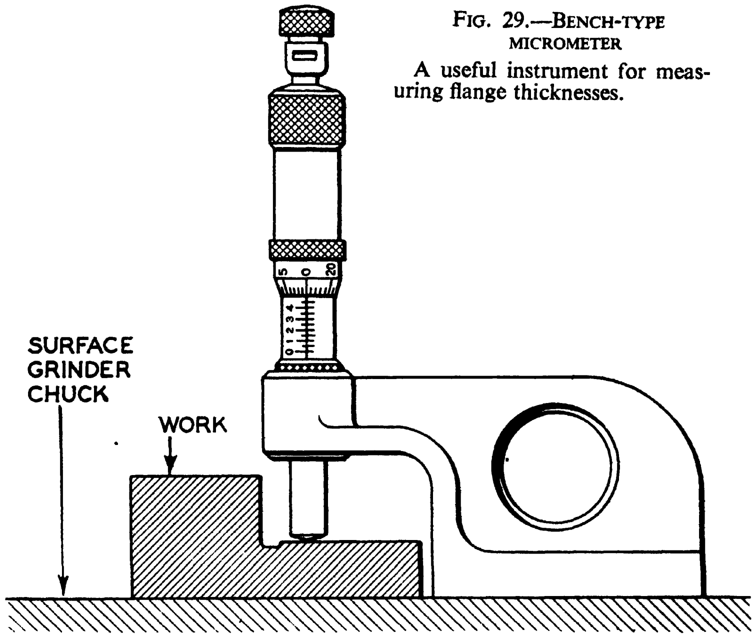


FIG. 29.—BENCH-TYPE MICROMETER

A useful instrument for measuring flange thicknesses.

testing, distances, centres, square or angular conditions are ascertained. Marking follows, and the operator begins to outline where portions must be turned, bored, drilled or surfaced in some way or other. Pieces rest directly on the plate, or may have to be steadied and adjusted by wedges, jacks, or special forms of support.

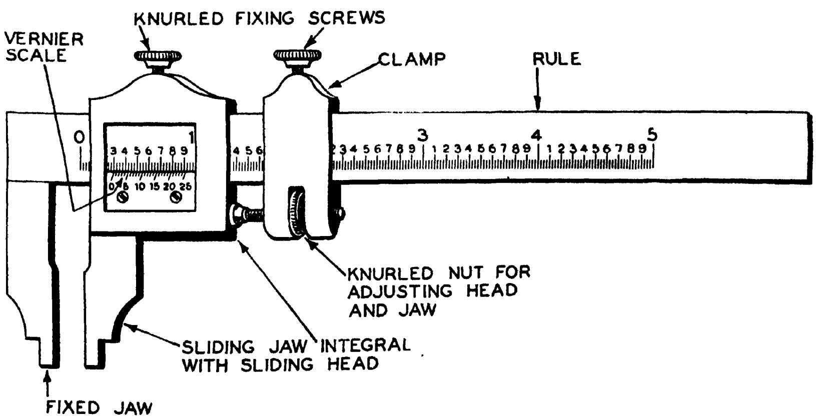


FIG. 30.—THE VERNIER CALLIPER

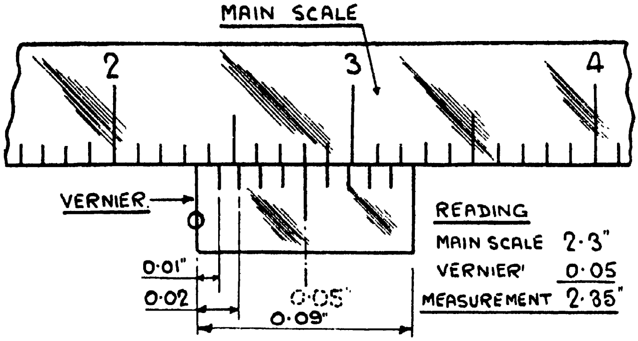


FIG. 31.—VERNIER MICROMETER SCALE GRADUATION

Measurement of Angles

The fitter has from time to time to mark off angles to a high degree of accuracy. The following are the chief methods used:

THE TRY SQUARE.—The back of the blade of this most useful appliance is used for testing the flatness of a filed or machined surface, whilst the interior angle of the square tests whether two adjacent edges or surfaces are at right angles. It is important that the try squares used for testing are accurate. The back of the blade can be tested for alignment by drawing or scribing a line, using the back of the blade as a guide. The blade should then be reversed and placed on the opposite side of the line, and it should now be possible to draw a line coinciding exactly with the first.

THE COMBINATION SQUARE.—Fig. 33 shows a typical combination set, consisting of the blade *A*, the try square head *B*, the centre square *C*, and the protractor head *D*. The head *B* contains a scriber *E*, and also a small spirit-level *F*. The protractor head also contains a spirit-level *F*. In general, only one fitting will be left in position on the head.

The uses of a combination square are very varied. It can be used as a steel rule, when the three fittings are removed from the blade. With the head *B* in position, it may be used as a try square or as a depth gauge. The protractor head may be clamped at any angle by means of a knurled screw. The revolving turret of the protractor is graduated from 0° to 180°, and can be read in both directions.

The centre square is most useful for marking lines on circular work, such as the ends of a bar which is to be mounted in the lathe. In order to find the centre, it is only necessary to scribe two lines, approximately at right angles, across the end of the bar, and the intersection of these lines will give the centre of the circle (Fig. 34).

BEVEL GAUGES AND PROTRACTORS.—The bevel gauge (Fig. 35) is particularly useful for measuring angles which cannot be measured directly by the protractor. The principle involved is similar to that of inside and outside callipers; just as callipers can be placed inside a tube or used to span an external diameter, so a bevel gauge can be applied to angles inaccessible to the protractor. The

FIG. 32.—SURFACE PLATE AND MARKING-OFF TOOLS

bevel gauge, when it has been correctly set, must then be applied to a protractor, so that the angle can be read off. In a combination bevel (Fig. 36) the split blade is hinged on the stock, and an auxiliary slotted blade can be clamped in any desired position by means of a milled nut.

For accurate measurement of bevels, the vernier bevel protractor is sometimes used. This consists of a straightedge with a circular angle scale fixed to it, to which is pivoted an arm carrying a vernier. By use of the scale, the arm can be set at any desired angle to the straightedge within an accuracy of $\frac{1}{12}°$.

THE SPIRIT LEVEL.—Fig. 37 shows an adjustable level which, in addition to finding the horizontal, gives the variation of any surface from the horizontal.

THE SINE BAR.—The sine bar consists of a steel bar with two projecting circular pins, the centres of which are set 5 or 10 in. apart. Measurement of angles by the sine bar method depends upon the trigonometrical formula applying to right-angled triangles:

$$\text{Sine of an angle} = \frac{\text{Opposite side}}{\text{Hypotenuse}}$$

The sine bar is usually arranged so that the accurate length between the two pins (5 or 10 in.) forms the hypotenuse, or longest side, of a right-angled triangle, as in Fig. 38. The difference between the two pins is then measured as accurately as possible (in Fig. 38, *a–b*). This difference is then divided by the length of the hypotenuse (the sine bar) and by referring to a table of natural sines the measurement of the angle can be found. There are other types of sine bar, such as one in which the pins are replaced by V notches, but the principle of use is the same as that of the ordinary sine bar.

Operations of Lining Out

Means for testing horizontal or vertical faces and marking lines comprise the scribing block, indicator, vernier height gauge, and square; angular positions require a bevel and bevel protractor.

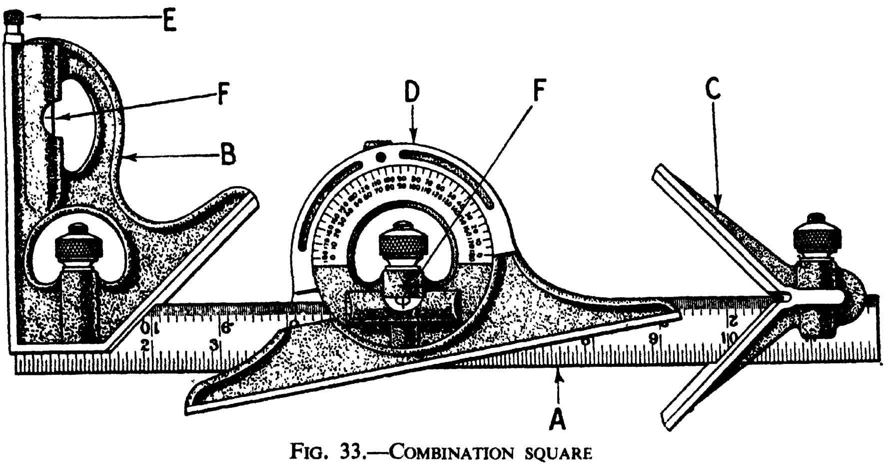


FIG. 33.—COMBINATION SQUARE

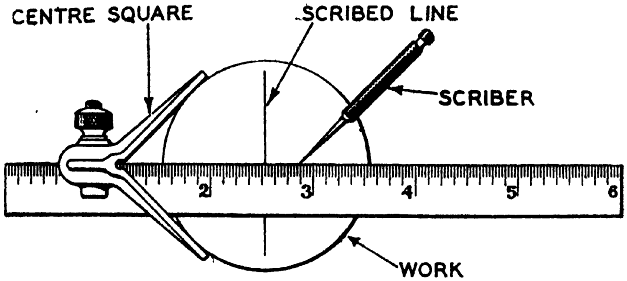


FIG. 34.—USING THE CENTRE SQUARE TO FIND THE CENTRE OF A CIRCULAR BAR

To make scribing lines visible, it is often necessary to rub the surface with chalk, or preferably with a mixture of whitening, shellac, and methylated spirit. On bright steel a solution of copper sulphate and water, with a very small quantity of sulphuric acid, may be used.

Usually the first operation when a piece has been placed on the table is to mark centre lines horizontally and, if necessary, vertically, and use these as a starting-point for the marking out. Distances above and below can be set off with dividers and scribed along with a scribing block, shown in Fig. 39. If the lines have to be placed on surfaces which do not lie in the same plane, the scriber needle is set to the desired measurement by means of a combination square or a rule clamped vertically in a block resting on the table, and is then transferred to the work (Figs. 40 and 41). The vernier height gauge, which has a foot to keep the rule vertical and a sharp marker clamped on a moving jaw which can be set to fine divisions of the inch or millimetre, can also be used.

To find the centre distance from hole to hole, small holes are plugged with discs of wood, lead, or white metal, and larger holes are spanned with bars of wood, lead, or steel.

Centre pops, most conveniently made with an automatic punch, can be made on lines or circles to prevent trouble due to the rubbing away of scribed lines.

Setting up Jobs by Touch and Test Indicator

The surface gauge scriber has one end turned over to 90°, and this end is used for setting up jobs by touch instead of by eye. It may be necessary to place a job on the table so that one surface is in the same plane as the table itself

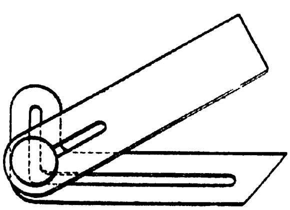


FIG. 35.—SIMPLE BEVEL GAUGE

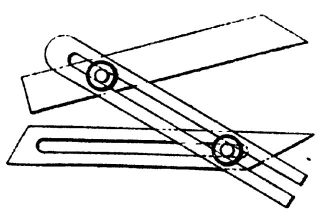


FIG. 36.—COMBINATION BEVEL

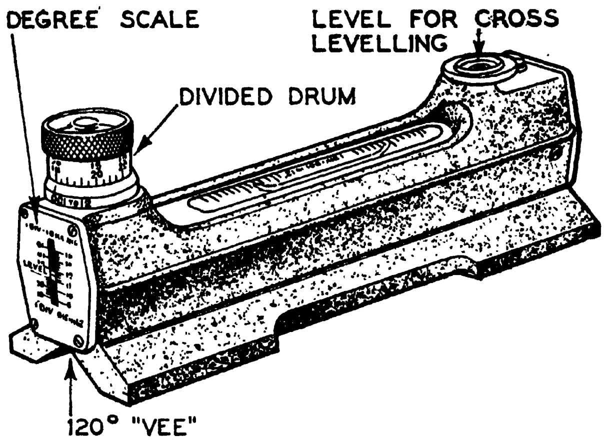


FIG. 37.—ADJUSTABLE SPIRIT LEVEL

(Fig. 42). The job is set up by eye in the first place, with the point of the scriber turned downwards and touching some point on its surface. The gauge is then moved to another part of the surface to see whether or not it touches there. A feeler (a strip of steel about 0·0015 in. thick) helps the sense of touch; the strip is placed under the point of the scriber, while the base of the surface gauge is held down, and is then pulled out. The effort required should be equal at every place that is tried.

Recent practice has simplified trials of this description, for the test indicator, an instrument clipped on to the scriber of the surface gauge or having a stand and arm of its own, offers precise and sensitive comparison (Fig. 43).

Templets and Jigs

As mentioned, templets save having to mark out duplicated articles individually; they are used, for instance, for holes for flanges and facings, ports for

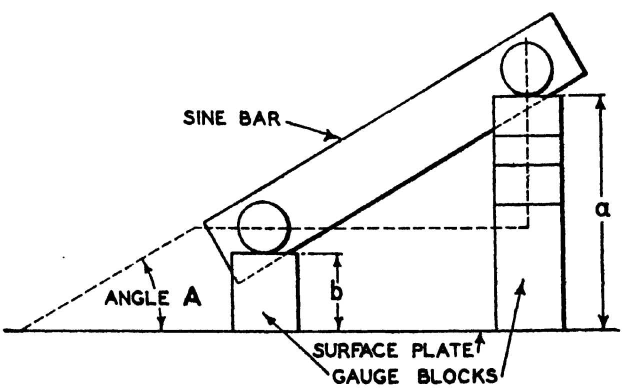


FIG. 38.—HOW THE SINE BAR IS USED TO SET UP AN ANGLE

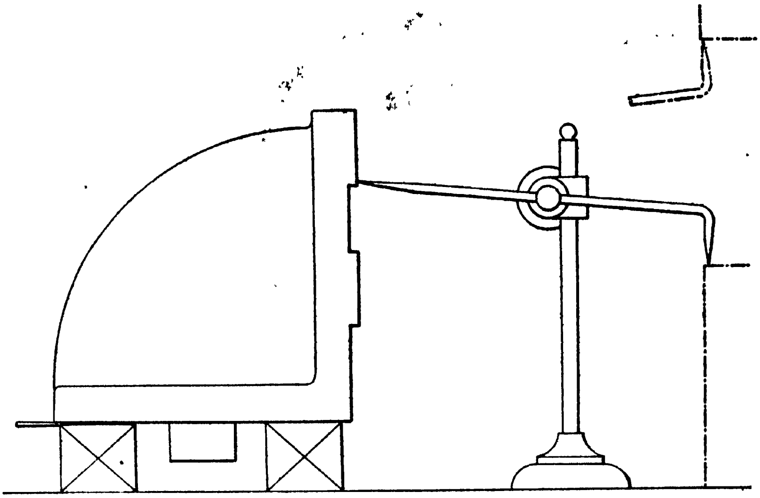


FIG. 39.—APPLICATIONS OF THE SURFACE GAUGE SHOWING SCRIBING ON THE LEFT AND CHECKING ON THE RIGHT

valves, slots in rods, holes in levers, shaft keyways, and many other common requirements. Location is either by edges, just setting with the hands until the templet matches the part on which it is laid, or small nibs may be bent over to embrace the work edges and provide rapid and certain location.

Templets are not, however, used as much as they were formerly, because in practice jigs now fill so large a place.

FITTING OPERATIONS

Basic fitting operations, such as riveting, key, cotter, bolt, stud, and bearing fitting are covered in this section. Details of the procedure for relining bearings are also included.

Riveting

A moderate amount of cold riveting comes within the scope of most fitting shops, chiefly for sheet-metal objects, such as small lugs, straps, and covers. Certain pins, studs, shafts, and other details are secured by riveting over after a plain or screwed stem has been fitted into place.

The length of the rivet is important. If it is not long enough, the rivet will not hold, and if it is too long, it will be necessary to hammer it until the metal becomes crystallised and is liable to break under strain. For rivets up to about $\frac{3}{8}$ in. diameter, the extra length for riveting should be equal to about half the diameter; for larger rivets it should be about a third or a quarter. For cold riveting the hole should be drilled barely large enough to allow the rivet to go through easily, with as little clearance as possible.

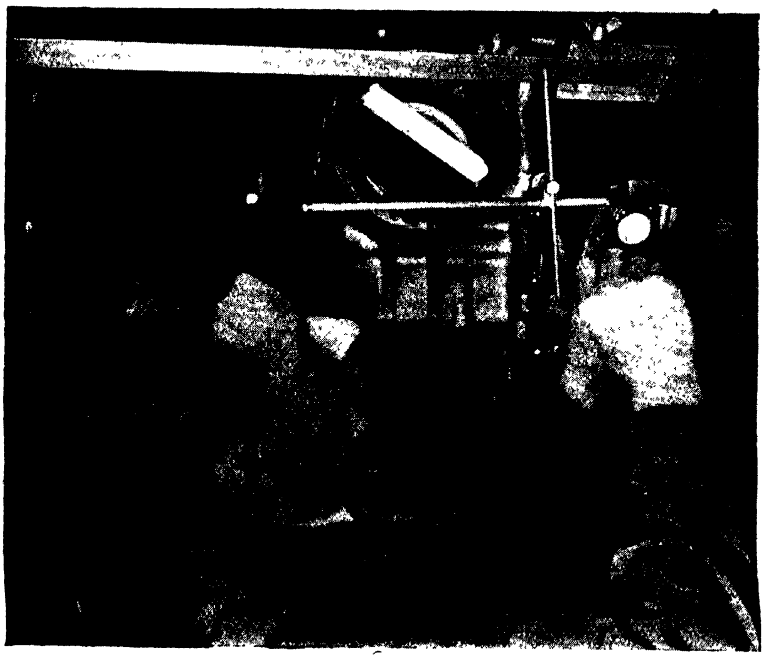


FIG. 40.—SETTING SCRIBING BLOCK
Sensitive adjustment is provided by a rocking lever moved by a screw.

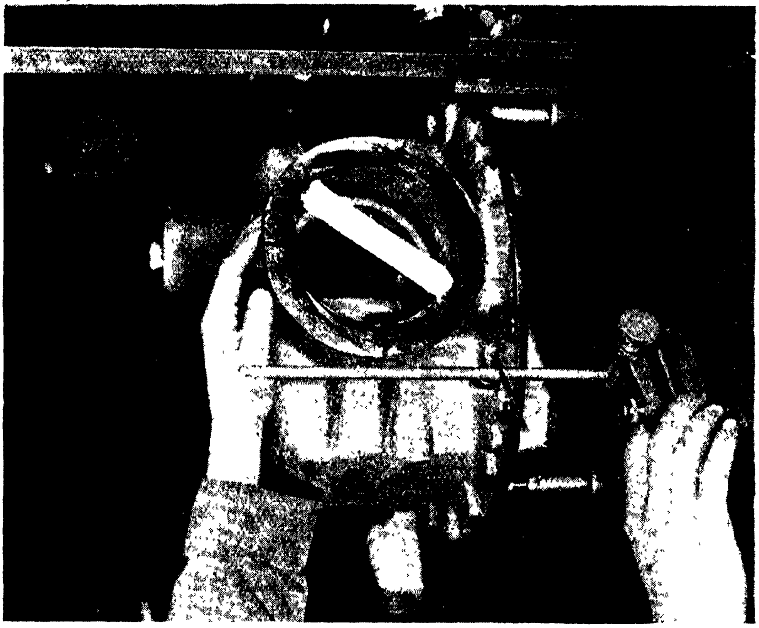


FIG. 41.—LINING OUT WORM-GEAR CASE
Illustrating the scriber in operation. (*A. E. C., Ltd.*)

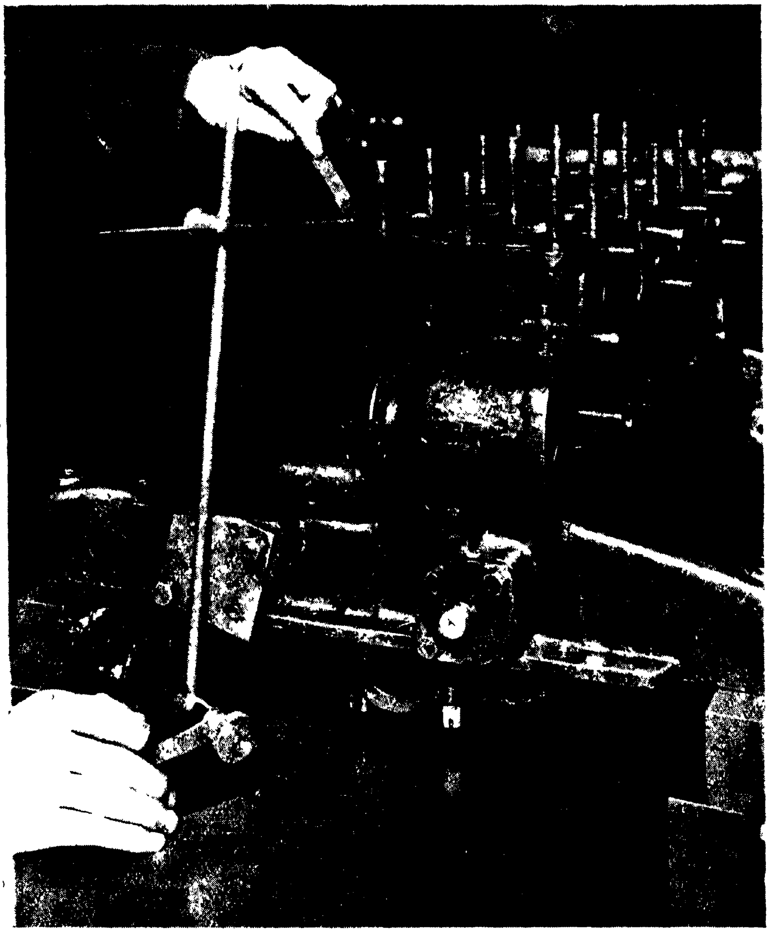


FIG. 42.—SETTING UP JOB HORIZONTALLY ON A TABLE

The main precautions are to be sure that the rivet or member is well up to its head, the joint faces are tight together, and the riveting over is not carried to excess. A small number of heavy blows are better than light ones prolonging the stress. Light and timid taps will only caulk over the extreme end of the rivet; it is the object of the operator to strike hard enough to swell the rivet in the hole before sealing over the end. The lightly tapped rivet will soon work loose, as it does not fill the hole. It is sometimes advisable to put oil on iron or steel rivets to keep them cool while hammering, or cracks will develop.

SETTING UP.—Joints must be firmly pressed or hammered together before attempting to rivet. Another way besides hammering or vice pressure is by

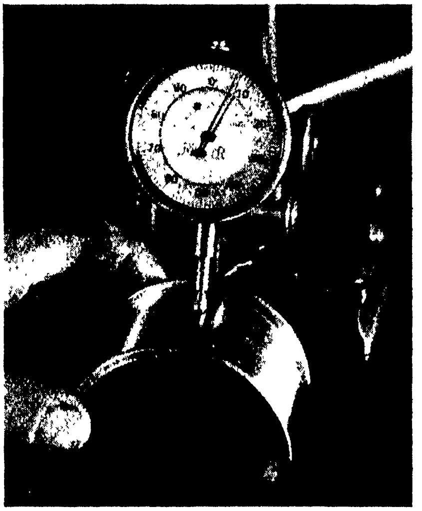


FIG. 43.—DIAL INDICATOR

means of a "set-up" tool (Fig. 44), with one end drilled to clear over the rivet. Where no other support is practicable for holding the rivet in position, a dolly is used. This is a heavy tool shaped at the end to fit over the formed head of the rivet.

MANNER OF RIVETING.—When riveting with a hammer, it is best to begin at the centre of the rivet, and, using the peen, spread the metal out until it fills the hole. The "feel" of the hammer as it strikes the rivet shows when it has been driven far enough.

FINISHING THE RIVET.—Fig. 44 also shows a snap to finish the head of the rivet neatly after it has been beaten down into approximate shape. If the snap is not being used to form the head, the flat face of the hammer should be used to finish it off.

BOLTING UP.—In some small jobs, where only a few rivets will secure the job, all the holes except the one to be riveted should be secured by bolts, each bolt being withdrawn as a rivet is inserted. The first rivet is likely to tip the job, so that when the opposite side is riveted a great strain is placed on the first rivet as the job is pulled back into place, and also unless the job is properly secured, the working faces are likely to creep, through rivets crushing over to one side.

Key Fitting

This, like some other of the processes, has been partially absorbed in the duties of the machine shop. In one way, ordinary keyways and keys are machined to close limits, leaving the fitting department hardly anything to do. In another direction, systems have been altered by adoption of solid splined shafts (having one or more raised keys) and broached hubs, the shafts and keys often being hardened and ground and nothing but assembly has to be performed.

A key may prevent both circular and longitudinal motion of the mating parts, or may permit the latter motion to occur. Some keys fit tightly along the top and bottom, some along the sides only, others on all sides. Fig. 45 depicts a selection of the more usual types, with their names.

PREPARATION OF KEYS AND KEYWAYS.—Generally, key beds are machined out ready for the fitter, and he is supplied with machined keys which only require a moderate amount of filing and scraping to fit. Exceptions arise when breakdowns and repairs have to be dealt with, or alterations effected *in situ.*

Then there may be necessity to cut keyways, and forge the keys, with chipping and filing to follow.

Much time is now saved by operating key-seaters that clamp on to a shaft or a wheel hub, as the case may be, and mill or slot the beds, drive being by hand, electric, or pneumatic motor.

Failing such aid, the position must be marked on the shaft ready for chipping, the tool for this purpose being a box square (Fig. 46), along the edges of which parallel lines can be scribed.

Sometimes a hole is drilled at each end of the predetermined length of bed for convenience of starting the chisel and obtaining a neat finish.

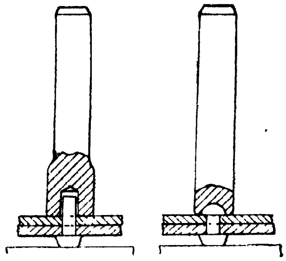


FIG. 44.—SET-UP AND RIVETING TOOLS

Chipping proceeds with a cross-cut, or a key-seating chisel (Fig. 47), straight all down the front.

When the groove has been roughed out as neatly as possible, a rough file straightens and flattens it.

This process is easier when the seat comes at the shaft end. Otherwise a flat or square file must be made red hot, bent as in Fig. 48, and rehardened. Stub files are handy for such work, as well as other grooving, and are gripped by the jaws of a handle with screw movement for tightening.

CUTTING KEY GROOVES IN BORES.—If hand cutting has to be done for a bore keyway (sometimes necessary when a new position must be given for the key in relation to a point around the hub), a square is laid against the face, the blade projecting into the bore, and parallel lines scribed. After marking the depth at each end, parallel or taper as needful, the keyway chisel comes into use, followed by the file.

Straightness is tested by a small rule as a straightedge, but a specimen key forms a good guide to ascertain truth, rubbing it with red-lead paste and noting the markings left in the groove when driven or pushed to and fro a few times.

KEYING SHAFTS.—When a shaft comes from the machine shop, the rough arris along the edges of the keyway must be removed with a smooth file.

The key should also have its sharp corners taken off; these are never any use, and give a false impression of tight fitting later. An ordinary drive key (refer to Fig. 45) is filed carefully along the sides, to just push into the keyways, finish by draw-filing being good both for accuracy and close fit.

FITTING KEY IN KEYWAY.—Next the shaft and wheel are assembled. Tentative fitting is one mode of procedure; the tip of the key is filed until it will enter, then more is taken off along the top and another trial made, driving the key in lightly with a hammer.

But it is quicker to calliper the height front and back (Fig. 49), and transfer these dimensions to outside callipers, as also seen, from which ledges may be filed down in the style represented. When the intermediate metal has been filed away, the key will nearly fit properly.

TRIALS FOR FIT.—As a steel key is liable to seize when driven tight, it must

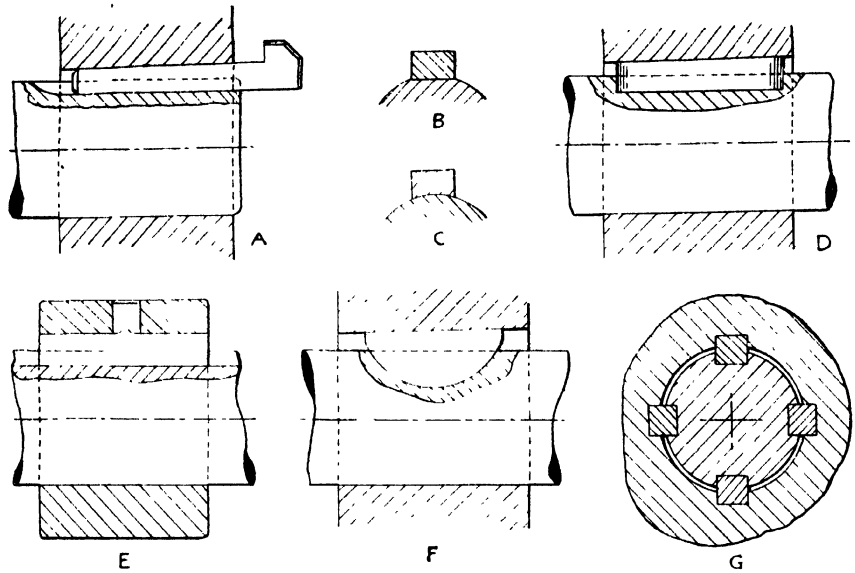


FIG. 45.—KEYS IN GENERAL USE

A, gib-head, also made headless and cylindrical headless; *B*, flat key; *C*, saddle key; *D*, feather key, light taper fit; *E*, pin, feather slidable; *F*, woodruff, light or slidable; *G*, stakes for centralising.

be rubbed with chalk or oil before insertion, red-lead paste being suitable for the concluding stages where it is desired to know the quality of fit. This shows as lines (Fig. 50) or bright spots, and a well-fitted key should have them all over. For good work, scraping will ensure the closest degree of contact. The more excellent this state the better for endurance; a key touching only on a few small areas soon becomes compressed and loose, especially for a reversing drive, and has to be driven in farther so that the limit of retightening quickly arrives.

FITTING SLIDING FEATHER KEYS.—This sort, over which clutches, gears, and other details slide, is sometimes secured to the shaft by screws or rivets. Fitting first the ends, which require to be smooth filed until of correct length, the sides are next attended to, until the key will nicely drive down to a firm bed.

After drilling the holes, tapping those in the shaft, removing burrs and assembling, the quickest practice is to calliper across from the wall of the bore to the keyway, transfer the dimensions to outside callipers, and use these to test filing down at each end, as already described for taper keys (Fig. 51).

Removing the intermediate metal, one commences final fitting by driving the sliding member along with a mallet, raw-hide hammer, or a block of hard-wood laid against the boss and struck with a hammer. Oil must be put on shaft and key for prevention of seizing.

After driving on with moderate force, the part is driven back and the key examined for marks. According to these, further filing is done, and more trials

given, scraping being best for the final close fitting. This is important, for unless the key fits closely all over, it will soon work loose under duty.

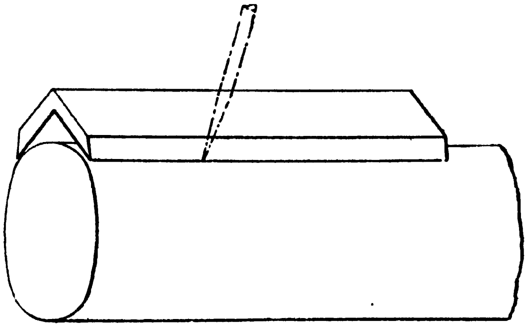


FIG. 46.—BOX SQUARE FOR MARKING OUT KEYWAY

Key Removal

Methods of abstracting keys depend on accessibility. If the tail can be reached, a drift (Fig. 52) is very efficient, three or four smart hammer blows effecting dislodgment. It is perhaps advisable to lay a curved bit of sheet-iron over the shaft at the end of the keyway to prevent the drift from burring it down.

HOOKING OUT.—When the tail is concealed (Fig. 53), alternatives consist of hooked tools and wedges. The first specified may be an old spanner, damage to which does not matter. It is used as shown in the figure just mentioned, being struck with a fairly heavy hammer where the arrow is seen. Proper key extractors may be purchased, made long to give powerful leverage for hooking out. Should the key head be too close to the boss for insertion of the hook, the tapered end is used as a wedge for a start. Hammer-driven wedges are applied as shown in Fig. 54, interposing a piece of packing when the key has moved out to the limit of the wedge thickness. If the key overhangs the shaft end, difficulty arises through bending down under the wedge action, consequently a heavy sledge hammer must be held under the head to support it. The extractor illustrated in Fig. 55 provides a rapid and neat way without damage to the key. The latter has two small grooves cut in it, as seen; the jaws grip into these by

FIG. 47.—KEY-SEATING CHISEL

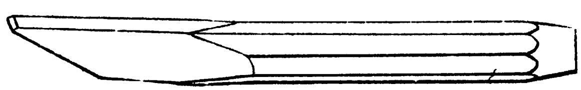
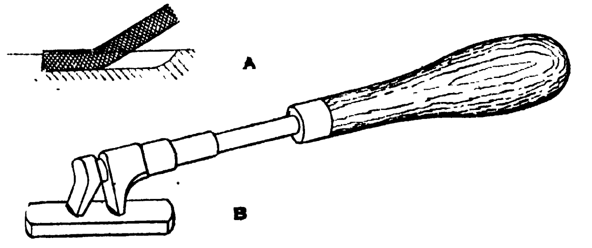
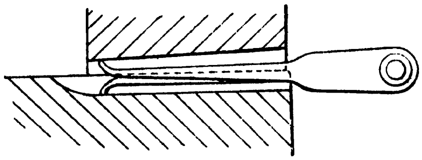


FIG. 48.—FILING KEYWAYS

A, square file bent to work in keyway; *B*, holder which takes stub file for similar duty.





pressure of the lateral screws, then the nut being turned, the key is bound to come out.

Fitting Cotters

This is a good test of the fitter's skill, as cottered joints are generally subjected to severe pushing and pulling, with sudden jolts and variations in pressure, particularly in engines and pumps. Poor contact of the fitting parts, therefore, soon results in compression and loosening.

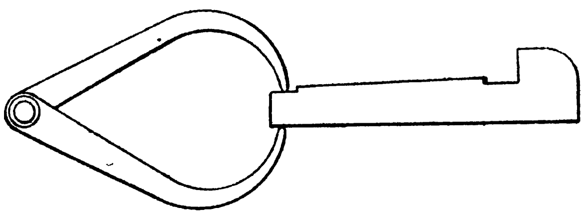


FIG. 49.—METHOD OF FILING KEY IN KEYWAY

Considerable variety is met with in forms and modes of application. Some are just a driving fit, to secure a rod into another part; others are locked by a split-pin or a side screw, while frequently the cotter has a screwed tail for this purpose. A cotter serves as an adjusting agent in connecting rods, drawing one brass against the other. By insertion of packing behind the brass, the distance from centre to centre may be kept constant, regardless of the effects of wear. When a forged strap embraces a rod end, the cotter requires a gib next to it to prevent the strap from spreading. Specimen fittings are outlined in Fig. 56.

PREPARATION FOR FITTING.—Taking a common example, that of a crosshead attachment, the first duty is that of marking out the cotter-way in the rod. When machine-shop routine is so accurately arranged that all dimensions are worked to closely, the fit of the taper end of the rod in the crosshead can be depended on to bring the cotter-way a definite distance along in relation to the openings cut in the head. But for general production, the usual plan is to drive the rod into place, and then find the location for the slot by scribing through. This shows as in Fig. 57 (*A*), but slot drilling must be done according to the dotted lines, giving the necessary tightening effect of the top end and freedom at the bottom.

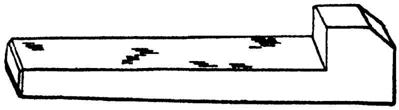


FIG. 50.—MARKINGS ON KEY AFTER TRYING FOR FIT

CHAMFERING.—After slot drilling, the surrounding metal each side should be chamfered (Fig. 57 *B*), to prevent burring and consequent seizing in the crosshead.

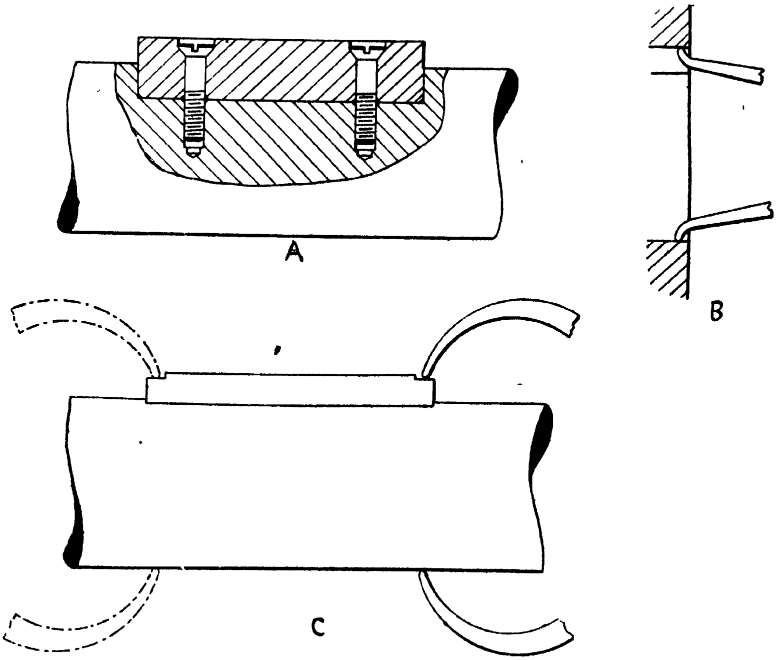


FIG. 51.—METHOD OF FITTING FEATHER KEY TO SHAFT

A, feather key fitted and screwed to shaft. *B*, callipering size to file feather. *C*, result of measurement transferred to outside callipers, these being applied to reduce ends of feather.

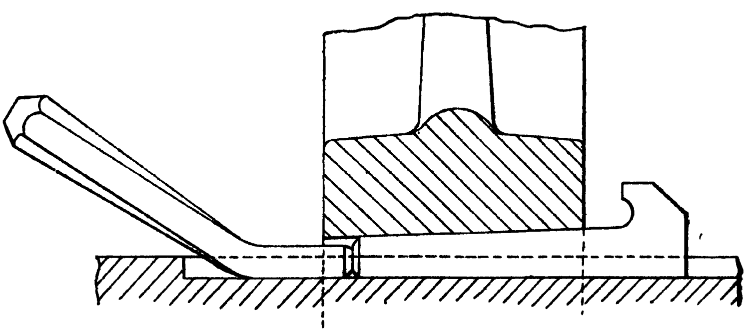
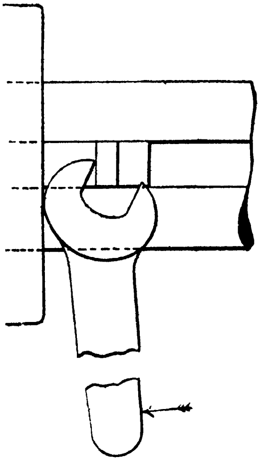


FIG. 52.—REMOVAL OF KEY BY MEANS OF DRIFT AND HAMMER



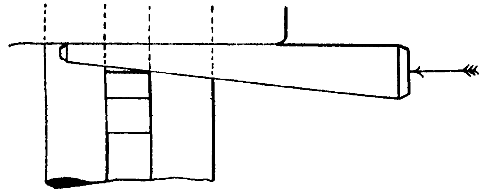


FIG. 53 (*left*).—HOOKING OUT A KEY BY MEANS OF A SPANNER

FIG. 54 (*above*).—DRIVING WEDGE BETWEEN BOSS AND KEY TO WITHDRAW KEY

FITTING THE COTTER.—The cotter, already forged and ground roughly to outline, has to be filed on the sides until it will just slide without shake in the slots when the rod and head are apart. The bottom of the cotter is filed to the half-round contour, and tried in the head slots with red-lead to test the accuracy of contact. If necessary, draw-filing is done to make the contact perfect.

Fig. 58 details the mode of filing the draft or taper at the one end of the slot, applying callipers set to the high and low distances for ascertaining the condition, or using a bevel gauge.

The top side of this also needs filing to the correct taper, as tried by calliper-ing, or a bevel or taper gauge, and it may now be started in the assembled rod and head. When putting these together, a narrow strip of steel of the same thickness as the cotter requires to be passed through the slots in order to keep them mutually in line until the rod has been set into position. Fitting is now a matter of driving the cotter in as far as it will go, removing, inspecting the marks on it, and filing a little for another trial. Red-lead smeared on will show up where contact has occurred. Care should be observed to preserve the straightness of the top, and the proper taper, thus making sure that the cotter will fit all the way along the taper in the rod. The small end of the cotter should project sufficiently for a split-pin to pass through.

CYLINDRICAL COTTERS.—To simplify fitting, a favoured practice is that of using a round parallel cotter passing through a drilled hole, the body having a taper flat to tighten against the part which requires locking. For binding tool shanks, the stems of tool bars, and some other elements in machine-tool construction, flatting is avoided, the cotter being formed with a concavity matching the curve of the hole, so gripping the shank without bruising it (Fig. 59). Better still is the use of a bolt or cotter with curve at the head, and a bushing, thus exercising an equalised pressure above and below, also evident in the same

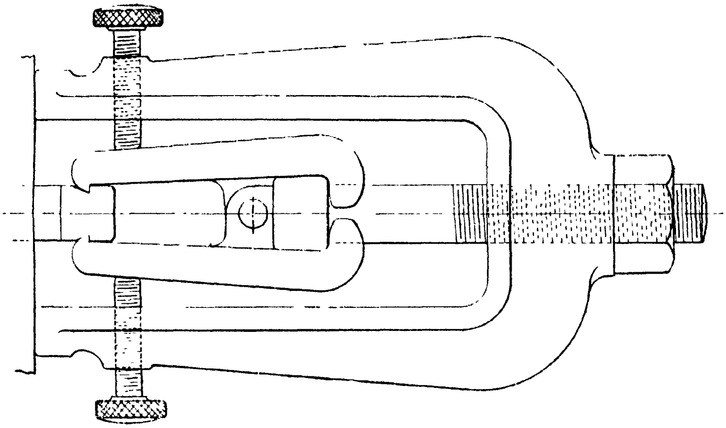


FIG. 55.—EXTRACTOR FOR REMOVING KEYS

illustration. Or the bolt may carry two bushes, curved to match the circle above and below the centre.

Bolt and Stud Fitting

Work in connection with the fitting of screws, studs, and bolts has been greatly reduced by machine-shop processes, but much hand-treatment persists, especially in the smaller shops and on repairs. Necessary operations comprise drilling, reaming, countersinking, counterboring, tapping, screwing, and stud setting.

DRILLING.—Most drilling occurs in the machine shop, but may be done by the fitter when positions cannot be determined at the time of machining, or, when it is easier to do so, in the fitting or erecting department.

A considerable proportion of holes are transfers, that is, a drilled casting or forging is placed in position and the location of holes in a piece to go under it is marked through with a scriber, or, if the member is deep, by either of the methods illustrated in Fig. 60. The first carries a scratch needle to mark a true circle, the other is a piece of tube brushed with whitening solution, so that when turned it leaves a circular impression. A centre punch can also be prepared to fit the hole accurately, thus enabling a pop to be struck for starting the drill.

Having thus struck a circle, the operator uses compasses to find its centre, and applies the centre punch to give an impression for starting the drill. If the drill point is started out of centre, it may be "drawn" over by driving a punch impression, as shown in Fig. 61. Very often the drill can be put through the part sent from the machining department, so that no marking is necessary.

TAPPING AND REAMING.—These operations, described on pages 163 and 164, may be required. Reaming is usually unnecessary unless the bolts, screws, rivets, etc., must fit closely, or unless it is required to line up and straighten two or more rough drilled holes in mating parts.

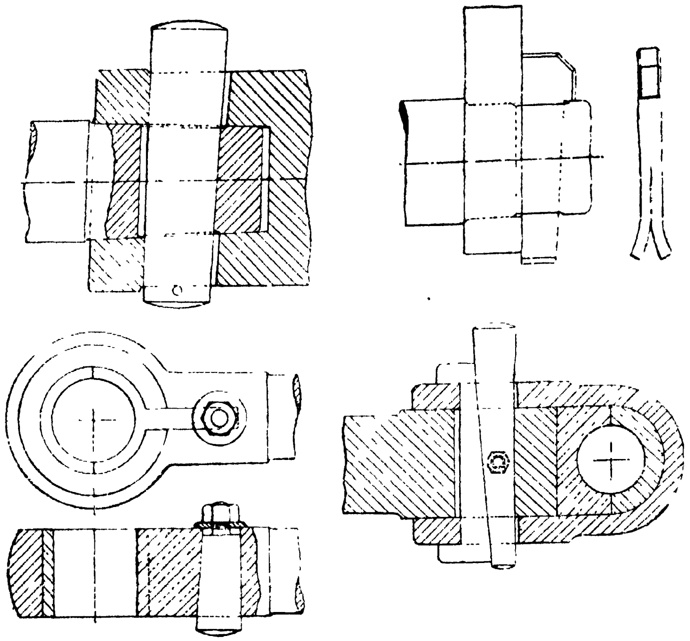


FIG. 56.—EXAMPLES OF COTTERS USED AS FASTENING AND ADJUSTING AGENTS

FIT OF BOLTS.—The roughest, cheapest sort of fit is by black bolts—not machined on the body—going in cored, punched, or rough-drilled holes. Location is not certain with these, but may be determined by a shoulder or spigot contact of the mating parts, or by dowels, plain close-fitting pegs. Turned or ground bolts in reamed holes are the best method of union, and separation and re-assembly may be done at any time with certainty of accurate relations. Sometimes these bolts are just a push fit; in other cases they are driven or forced in tightly, occasionally, for severe duties, fitting by taper body.

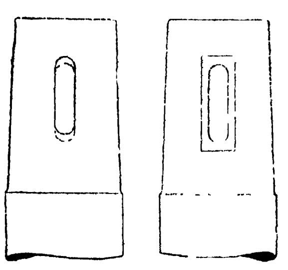


FIG. 57.—PREPARATION FOR FITTING COTTER IN CROSS-HEAD ATTACHMENT

A, dotted lines show actual terminations of slot drill travel in relation to lines scribed through a crosshead slot on rod. *B*, chamfer around slot to prevent burring.

FACING TOOL.—If surfaces around bolt holes have not been machined, and it is desired to have a true square facing for the turned head of a bolt, or its nut, the fitter employs a facing or arboring tool (Fig. 62), rotated by tap-wrench. The cutter is filed to shape, hardened and tempered, and the edges ground and honed to impart a smooth finish. Shouldered down to

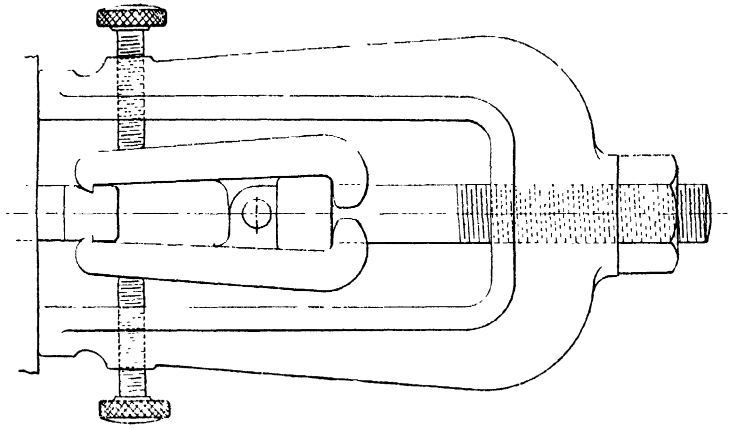


FIG. 55.—EXTRACTOR FOR REMOVING KEYS

illustration. Or the bolt may carry two bushes, curved to match the circle above and below the centre.

Bolt and Stud Fitting

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A considerable proportion of holes are transfers, that is, a drilled casting or forging is placed in position and the location of holes in a piece to go under it is marked through with a scriber, or, if the member is deep, by either of the methods illustrated in Fig. 60. The first carries a scratch needle to mark a true circle, the other is a piece of tube brushed with whitening solution, so that when turned it leaves a circular impression. A centre punch can also be prepared to fit the hole accurately, thus enabling a pop to be struck for starting the drill.

Having thus struck a circle, the operator uses compasses to find its centre, and applies the centre punch to give an impression for starting the drill. If the drill point is started out of centre, it may be "drawn" over by driving a punch impression, as shown in Fig. 61. Very often the drill can be put through the part sent from the machining department, so that no marking is necessary.

TAPPING AND REAMING.—These operations, described on pages 163 and 164, may be required. Reaming is usually unnecessary unless the bolts, screws, rivets, etc., must fit closely, or unless it is required to line up and straighten two or more rough drilled holes in mating parts.

has been fitted, a die-nut (Fig. 65) deals with bruised threads, cleaning them up neatly.

REMOVAL OF STUDS.—Two nuts locked together tightly on a stud will enable it to be abstracted, placing the wrench on the under one. Or, if damaging the stud does not matter, an old spanner and a piece of file (shown black, Fig. 66) causes positive rotation by the file biting into the metal. A tool designed for this function has an eye to drop over the stud, and the eye is pivoted to a long handle with a cam-shaped serrated end. On pulling at the handle the serrations dig into and turn the stud.

The Fitting and Adjustment of Bearings

Good fitting and maintenance of shaft and spindle bearings is of vital importance in most classes of mechanism. The hand fitting of bearings is only necessary when accurate boring equipment is not available, but the fitter may have to treat a worn bearing by rebushing the bearing surface or running-up with white metal.

The main points the fitter must take into account depend upon whether the bearing is a solid (or dead-eye) shape, or whether there are divided "brasses"; also, if adjustment is obtained by means of bolts or screws, or if there is more elaborate contractile effect with a bushing opened or closed by some sort of screw or wedge device.

FAULTS.—A properly fitted brass must bed well in the housing, and the shaft must make contact all over the bore. Faults which may require correction concern want of true circularity in the seatings, because of springs in the boring-bar; and similar inaccuracy in the brasses on leaving the lathe. Brasses run up with white metal may also be untrue from distortion induced by the heat. The first proceeding is that of filing off the sharp edges where the seating meets the end faces, so that the brass (which often has a radius in the angle) will not make a false impression of fitting. The faces next require touching off with a smooth file until the flanges of the brass will slip over them snugly (Fig. 67). Any faults found in lack of proper contact of the respective curves are generally more easily corrected by filing the brass. To find where the contact spots are, the bed is thinly smeared with red-lead paste, the brass is put in place, and twisted to and fro in a short arc.

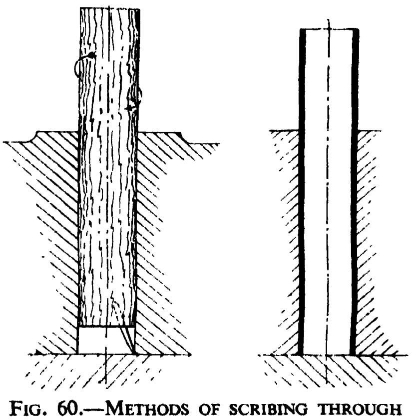

FIG. 60.—METHODS OF SCRIBING THROUGH DEEP HOLES ON TO SURFACES FOR DRILLING

The end of the tube in the right-hand example is smeared with colouring matter.

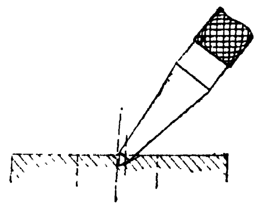

FIG. 61.—CORRECTING A DRILL POINT WHICH HAS BEEN STARTED OUT OF CENTRE

TRYING IN THE SHAFT.—There may be only two bearings, or several in line to support the shaft. After taking off the sharp corners of the brasses the shaft is laid in the lower halves; generally the safer plan is to try each half-brass on the shaft, in case it is tight across the edges (Fig. 68). If tightness is present, the difficulty may be remedied with a fine half-round file, or a scraper, according to the amount requiring removal, until proper bedding occurs. Marking is rubbed on the shaft, so that by its transference to the brass the places of contact will be shown. Filing need only be resorted to in very bad cases, the scraper being usually sufficient. By its use a considerable quantity of metal can be taken off, or an extremely fine amount, with a high degree of smoothness. The direction of motion appears in Fig. 69. A double-handled tool (Fig. 70) moves in a similar way, the fitter drawing it towards him for the cut, and is used chiefly for finishing. Only a very slight curve is ground along the edge, which serves to obliterate any high portions left from the other scraper which has roughed out the bearing.

COMPLETION OF FITTING BEARING.—When the shaft has been well bedded down in the lower brasses, the caps are laid on, pulled down gently by the nuts, and rotation tried. The shaft will probably be too tight to turn, so scraping must be done in the cap when the hard spots have been detected by means of the red-lead test, and continued, with intervals of trials, until the shaft will revolve by hand grip alone, making the best possible fit in the brass.

BUSHED BEARINGS.—In addition to several variations in arrangements of divided brasses to suit pressures acting in certain directions, with adjusting features not possible in ordinary styles, solid or split bushes are adopted very extensively.

Solid bushes are fitted to the shaft or spindle by scraping and trials with red-lead, as already described. A split bush may be contracted by the direct pressure of the bearing cap, or by screws fitted to it. Many bushes are tapered on the exterior to fit the eye of the bearing, so that when moved into the latter by nuts, contraction will occur. Occasionally the bush is solid, but cut with a series of longitudinal grooves inside and outside, so that it is sufficiently flexible to contract by the taper system. Sometimes the split of a bush is left empty, but frequently is filled with a wood or fibre insert to prevent vibration

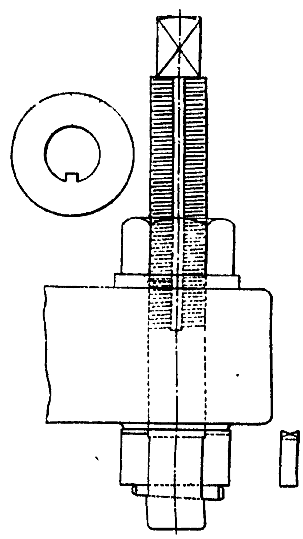

FIG. 62.—ARBORING OR FACING TOOL

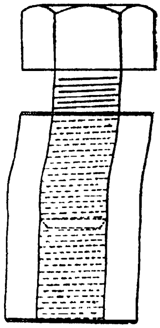

FIG. 63.—STUD BLOCK FOR SCREWING STUDS INTO PLACE

The block is screwed on to the stud by hand until the setscrew touches the top, after which a spanner applied to the body of the block will cause the stud to screw in.

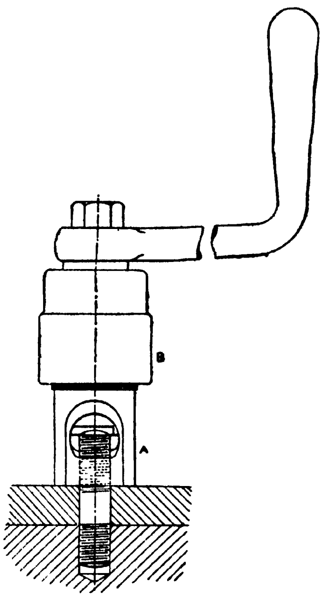

FIG. 64.—TOOL FOR ROUNDING OFF THE ENDS OF STUDS WHEN IN PLACE AND REDUCING THEM TO UNIFORM LENGTH

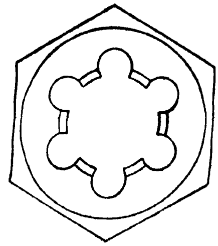

FIG. 65.—DIE NUT BY MEANS OF WHICH DAMAGED THREADS ON STUDS IN SITU MAY BE CLEANED UP AND SIZED

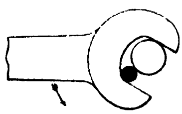

FIG. 66.—STUD REMOVAL

Using the biting-in action of the piece of file shown black.

and keep out dirt. Fig. 71 shows specimen splittings. Greater flexibility is afforded by the second and third arrangements than by the first, and more likelihood of concentric adjustment. Fig. 72 shows a parallel-nose screw at the right to prevent all movement of the bush, and two taper-nose ones at the left, to be retracted when take-up is necessary.

LINING BEARINGS WITH WHITE METAL.—A large proportion of the bearings employed in all classes of machinery are lined with white metal. Faults which may develop under various conditions are lack of good lubricating effect, inefficient anti-friction results, cracking, spreading, and deformation, which allows oil to penetrate between the shell and the white metal. A shell might possibly be cracked before metalling, but this could be ascertained beforehand by rapping it with a mallet or stick to get a clear note. The shells should be thoroughly cleaned of dirt, grease, scale, or old white metal, and in nearly all cases the surfaces to be lined should then be tinned to ensure that the metal will adhere perfectly. Fig. 73 shows the shell being heated by gas blowpipe, only at the back, because the flame must not be allowed to touch the surfaces to be tinned. Application of the solder is shown in Fig. 74, working all over the area, and over the ends, being sure that a good even coating is given. An

alternative method consists of dipping the shell in a pot of molten solder or tin.

POURING THE METAL.—In order to ensure intimate contact of the white metal with the tinned portions, preheating must be performed, applying the blowpipe as in Fig. 75, until the tinning will just begin to run. Then the metal is poured in gently and steadily (Fig. 76) until the space has been filled. An excess is necessary at the top to allow for shrinkage; this is provided for by a half-ring laid on top of the shell. As a means of preventing tin or white metal from adhering to any part of a shell but the bearing surfaces, a wash (of red clay and water, for instance) may be applied. Separating strips of steel have to be inserted between half-shells when poured simultaneously, and a clamp must be placed around the halves to bind them firmly.

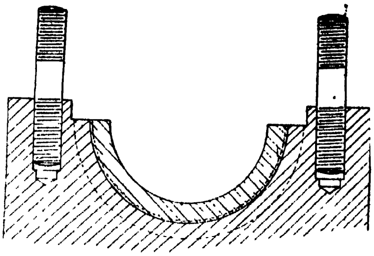

FIG. 67.—POPULAR TYPE OF BEARING BRASS

OIL GROOVING WHITE-METAL BEARINGS.—It is essential to distribute oil over the bearing surfaces by means of grooves leading from the supply hole or holes, and varied dispositions are found in different kinds of bearings. Care must be taken not to make grooves too wide or extensive, thus reducing effective bearing area.

Usually the edges of brasses are chamfered along to within a short distance from the ends, with the object of preventing a scraping action on the shaft, and so depriving it of a good oil film. Instead, the chamfering forms a pocket in which oil collects and smears the shaft efficiently. Fig. 78 shows this bevelling, which is chipped and filed, or filed only in small sizes. When produced by hand, the round-nose or oil-groove chisel is employed to chip the grooves, and they are finished smoothly with a round file bent up at the end for convenient manipulation.

LINE REAMING WHITE-METAL BEARINGS.—The more difficult sets of bearings, where several must come in perfect alignment, are often fitted without scraping by a hand-operated reaming outfit. This refers particularly to aero and motor work, both for construction and repairs. Instead of bolting the crankcase on a machine, it is laid on a bench or stand, and the reaming bar turned with a handle. The extensively adopted Martell line reaming system embodies three elements—an accurate aligning bar, coned centring bushes, and adjustable reamers. The reamer blades (Fig. 77) rest upon wedges, shown in black, and are moved to the right by means of the left-hand nut for expansion, the other nut being slackened off accordingly. The centring bushes, *A*, have a fine thread on the cone, enabling it to be screwed into the bearing firmly. The inner bushing, *B*, fits centrally by its tapered part within *A*, and in the position shown brings the bar concentric with the bearing. *A* can be adjusted

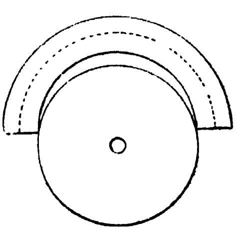

FIG. 68.—TRYING BRASS ON SHAFT BEFORE FITTING

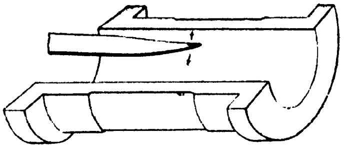

FIG. 69.—MOVEMENT OF HALF-ROUND OR TRIANGULAR SCRAPER

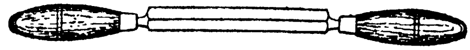

FIG. 70.—DOUBLE-HANDLED TOOL

This has a triangular blade which is ground with a very slight curve along the length. The scraper is for smoothing down equalities left from other scrapers.

either up or down or sideways on manipulating the four knurled screws as required, and thus the position of the bar is capable of variation, affecting the alignment of the reamers.

CLOSE FITS TOLERANCES

A considerable proportion of fitting practice is concerned with making various kinds of close fits for shafts, spindles, pins, bolts, bushes, liners, collars, rings, washers, and other component parts.

Measurements used to be taken with ordinary callipers, and each shop had its own idea as to the allowances desirable for the fit. Now standard fits are all classified, and precise results are obtained by means of micrometer callipers and various snap or limit gauges. This not only ensures uniform results, but materially assists the fitting department and permits of interchangeability.

There are two systems of classifying fits used in this country, the Newall System and the B.S.I. System.

The Newall System

In this system the various allowances are known by symbol letters. For holes, two classes or qualities are arranged, *A* and *B*, depending upon the fineness of accuracy required. Class *A* is the finer of the two: for instance, on a 2-in. hole the tolerance is $\begin{matrix}+0{\cdot}00075\\-0{\cdot}00025\end{matrix}$, a total tolerance of 0·001 in., whereas n Class *B* the tolerance is $\begin{matrix}+0{\cdot}001\\-0{\cdot}0005\end{matrix}$, with a total tolerance of 0·0015 in.

For shaft tolerances, running fits are divided into three classes, *X* for easy fits where sufficient room for lubrication is required, *Y* for good average machine work, and *Z* for fine instrument and tool work. For example, on a 2-in. shaft the tolerances are:

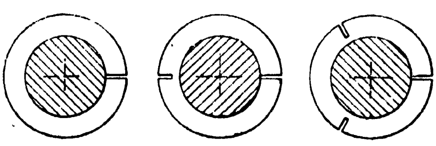

FIG. 71.—SPLIT BEARING BUSHES

Showing different means for take-up by closing in.

X: $\begin{matrix}-0{\cdot}0017\\-0{\cdot}0035\end{matrix}$, tolerance 0·0018 in.

Y: $\begin{matrix}-0{\cdot}0012\\-0{\cdot}0025\end{matrix}$, tolerance 0·0013 in.

Z: $\begin{matrix}-0{\cdot}0007\\-0{\cdot}0015\end{matrix}$, tolerance 0·0008 in.

There are also push fits, driving fits, and force fits. Push fits, Class *P*, will not be free enough to rotate unless force is used. Shafts made to the limits of driving fits, Class *D*, will require driving into their holes. Hydraulic force or heating will be required to mate force fits, Class *F*. On a 2-in. shaft the tolerances are:

$P\colon \begin{matrix} -0{\cdot}0002 \\ -0{\cdot}0007 \end{matrix}$, tolerance 0·0005 in.

$D\colon \begin{matrix} +0{\cdot}0015 \\ +0{\cdot}0010 \end{matrix}$, tolerance 0·0005 in.

$F\colon \begin{matrix} +0{\cdot}0040 \\ +0{\cdot}0030 \end{matrix}$, tolerance 0·0010 in.

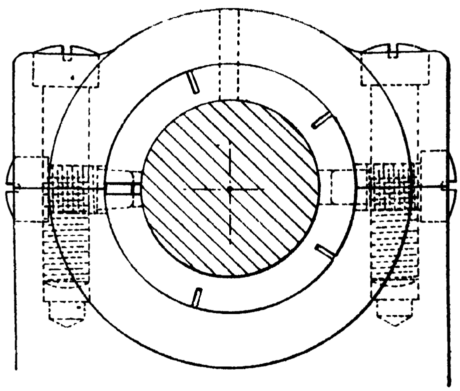

FIG. 72.—SPLIT BUSH CONTRACTED BY TIGHTENING THE BEARING CAP

British Standards Institution System

This system is based on the size of the hole with unilateral tolerances shown on the shaft. It is fully explained in B.S. 164 : 1924.

In this system, the holes are kept to standard sizes and suitable allowances are made on shaft sizes according to the class of fit required. It will be obvious that this system has much to recommend it, as it is much easier to vary the diameter of a shaft to within very fine limits than to vary the diameter of a hole to within equal limits of accuracy.

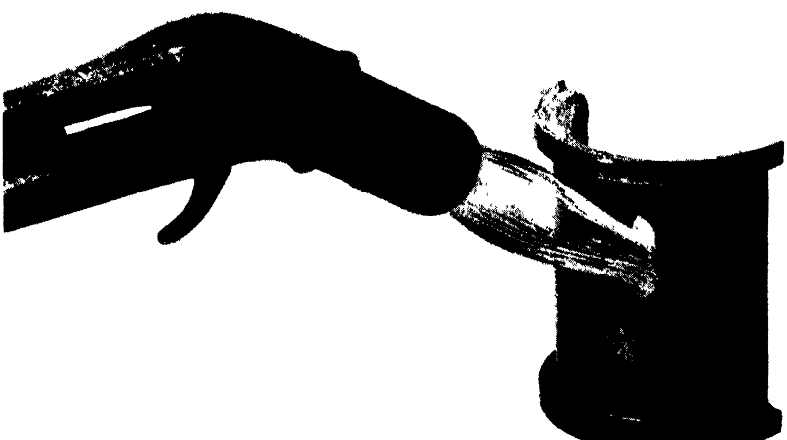

FIG. 73.—HEATING A BEARING SHELL PREPARATORY TO TINNING
(*Hoyt Metal Co., Ltd.*)

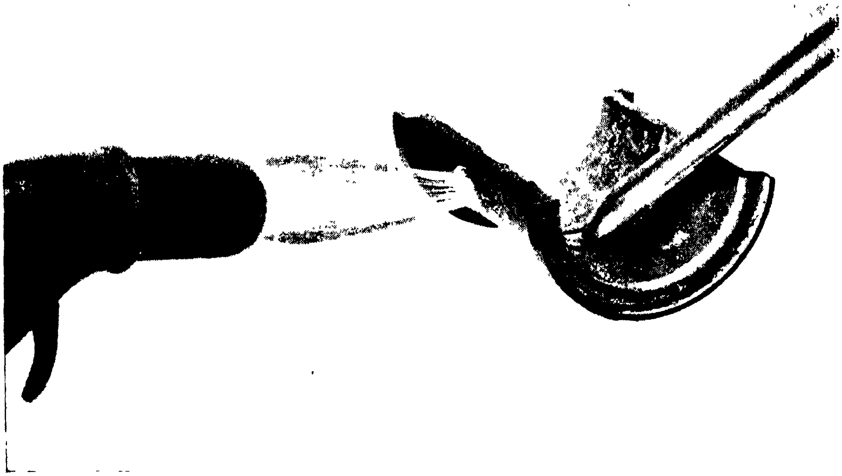

FIG. 74.—OPERATION OF TINNING THE SHELL
This ensures proper adherence of the white metal. (*Hoyt Metal Co., Ltd.*)

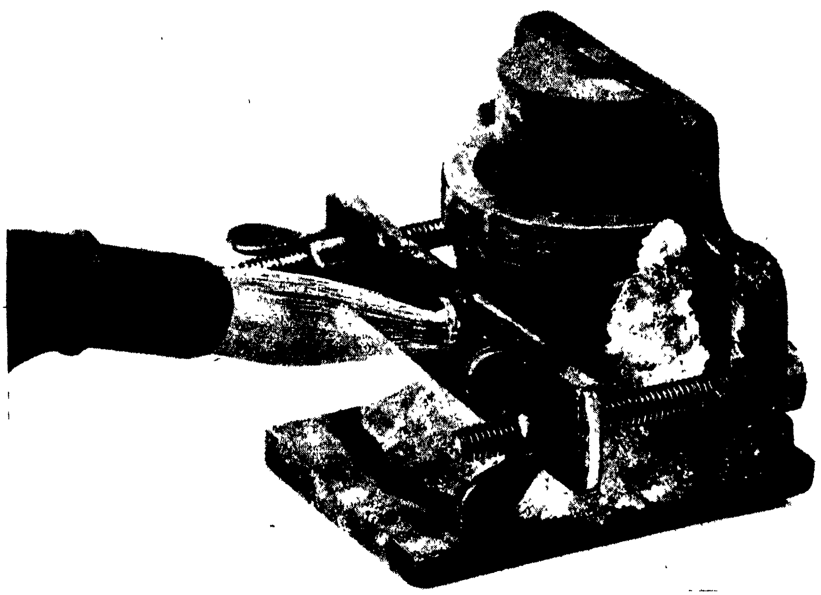

FIG. 75.—PREHEATING OF SHELL CLAMPED IN JIG
(*Hoyt Metal Co., Ltd.*)

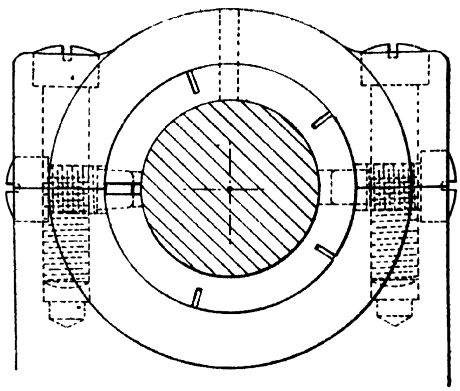

FIG. 72.—SPLIT BUSH CONTRACTED BY TIGHTENING THE BEARING CAP

There are also push fits, driving fits, and force fits. Push fits, Class *P*, will not be free enough to rotate unless force is used. Shafts made to the limits of driving fits, Class *D*, will require driving into their holes. Hydraulic force or heating will be required to mate force fits, Class *F*. On a 2-in. shaft the tolerances are:

$P: \begin{matrix} -0{\cdot}0002 \\ -0{\cdot}0007 \end{matrix}$, tolerance 0·0005 in.

$D: \begin{matrix} +0{\cdot}0015 \\ +0{\cdot}0010 \end{matrix}$, tolerance 0·0005 in.

$F: \begin{matrix} +0{\cdot}0040 \\ +0{\cdot}0030 \end{matrix}$, tolerance 0·0010 in.

British Standards Institution System

This system is based on the size of the hole with unilateral tolerances shown on the shaft. It is fully explained in B.S. 164 : 1924.

In this system, the holes are kept to standard sizes and suitable allowances are made on shaft sizes according to the class of fit required. It will be obvious that this system has much to recommend it, as it is much easier to vary the diameter of a shaft to within very fine limits than to vary the diameter of a hole to within equal limits of accuracy.

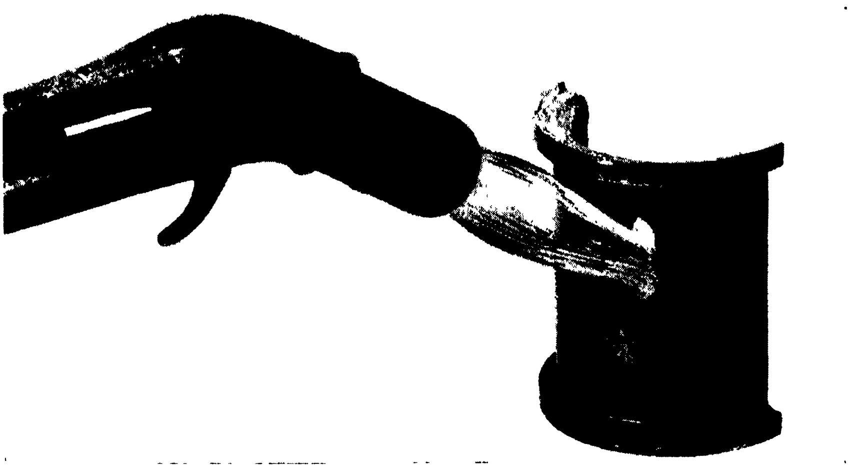

FIG. 73.—HEATING A BEARING SHELL PREPARATORY TO TINNING
(Hoyt Metal Co., Ltd.)

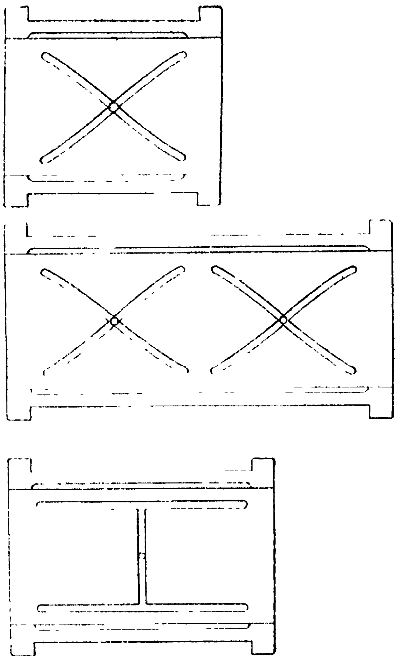

FIG. 78.—SPECIMENS OF OIL GROOVING

Methods of Making Close Fits

Methods vary according to the shape and size of the components, the relative tightness of fit, and whether a few or a large number of pieces have to be dealt with. The simplest way is by direct blows; other systems include bolt or vice pressure, screw, lever, pneumatic or hydraulic mechanism. A good deal of the forcing which was formerly accomplished by hammer or vice action is now effected in vertical presses.

PRELIMINARY TREATMENT.—Before commencing to put any pieces together, the character of the machining has to be taken into consideration. Working to the fine limits usual in good practice, there may be little or nothing for the fitter to do, but in some general shops, and on repairs and replacements, the file and scraper may be needed to ensure accuracy. Tentative fitting is perhaps necessary, and the hole may be enlarged with a smooth half-round file, or scraped, if very little has to come out. Care must be taken to have the surfaces perfectly clean and oiled before union. Short bushings and rings need careful starting to ensure they are set straight.

ASSEMBLY BY HAMMERING.—Much is done at the bench and on the floor with rawhide or wood mallets, with a sledge hammer and a lead, copper, or brass block for the final force necessary. A recess is drilled in the centre of the block to provide space for the upstanding bit of metal often left from centring for the lathe or grinder; this is cut away after the fitting is complete. Small work may conveniently be driven with a lead, copper, or brass hammer.

BOLT-PULLING DEVICES.—On pieces liable to injury by any sort of hammering, steady, equal, and powerful force can be applied by a simple rig-up of bolts and plates. Bolt arrangements for insertion and withdrawal are shown in Figs. 79 and 80, the bush being started in gently with a block of wood and hammer, and the bolt and plates then arranged.

PULLING WHEELS ON SHAFTS.—If there is no shoulder on a shaft against which to take a pull, bolts can be held as shown in Fig. 81. A clip is bolted on to the shaft; against this rest the bolt washers, so that the wheel can be forced along by turning the two nuts equally. When two such wheels come at opposite ends of a shaft, long bolts may pass through their arms and both be drawn on until the shoulder seatings have been reached. Alternatively, several designs of

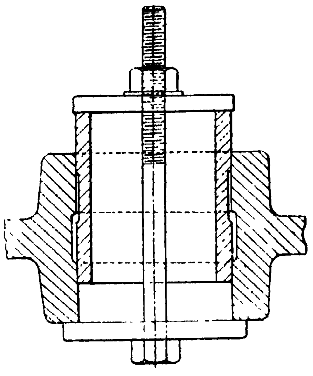

FIG. 79.—METHOD OF PULLING IN BUSH WITH NUT AND BOLT

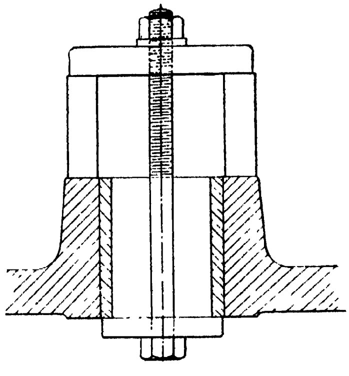

FIG. 80.—METHOD OF REMOVING BUSH WITH NUT AND BOLT

wheel-pullers are sold, with quick adjustment to suit different diameters of wheels, pulleys, gears, and flywheels.

FORCING IN THE VICE.—A vice may be used to press in pins, bushes, and other details with less injury than hammering may involve. Soft clams are usually required for protection, and a slab of wood or metal may be advisable to spread pressure uniformly all over the face of the bush.

ARBOR PRESS.—The ordinary vertical rack-operated press employed by turners and grinders has been found useful for light forcing. More powerful types have been made which force and extract with ease and accuracy. Many time-saving devices are used to locate components: a stop collar on the ram limits the downward movement, so that parts may be forced in a definite distance without attention from the operator, or rings can be used to act as stops, as in Fig. 82. To locate in a circular direction the ram can be arranged with a screw to enter a small recess in the spindle which slips up into the ram hole, the other element lying in a fixture on the table. Thus the spindle will be set correctly for pressing into the hole.

HYDRAULIC FORCING.—This is practised on a large scale, presses of either

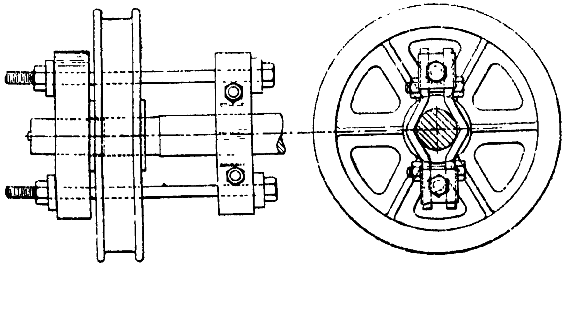

FIG. 81.—FORCING A WHEEL ON TO ITS SHAFT

By turning the nuts, the wheel is pulled along the shaft.

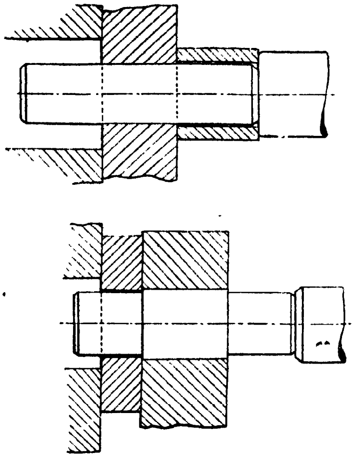

FIG. 82.—USE OF STOP RINGS FOR ARBOR PRESS RAM

(*Top*) Ring placed over a pin to determine the limit of forcing in by arbor press ram.

(*Bottom*) The under-ring acts as a stop for the shoulder of the pin being forced in.

vertical or horizontal build being used, fixed or portable. Hand, belt, or motor-driven pumps supply the pressure and quick adjustability, for distance of work must usually be incorporated. Hydraulic bolt forcers are obtainable, and also drum pullers, suitable for forcing drums off shafts; warping ends from winch shafts, discs or cranks from shafts, and crankpins from their holes.

BALL AND ROLLER BEARINGS

THERE are many types of ball and roller bearings often referred to as anti-friction bearings or rolling bearings, which consist essentially of two hardened-steel races with rolling elements interposed between them. The rolling elements are.of many different forms, the commonest being spheres, cylinders, trunkated cones, and barrels. The many types of bearings in which they are fitted are shown in the illustrations.

Single-row Rigid-type Ball Journal Bearing (Fig. 2)

This is the most widely used of all anti-friction bearings. The races are usually made with continuous track grooves, and the assembly is made by placing the two races eccentric to each other and inserting the balls into the intervening crescent-shaped space. The balls are then spread round the track and spaced by a suitable cage or separator. The latter may be machined from the solid or made from pressed sheet metal. This "no-gap" type of bearing is suitable for radial load and axial load in one or both directions or combinations of the two. The transverse radius of the track surface is only very slightly larger than the radius of the ball, so that under load there is an elliptical contact of appreciable area between them.

Sometimes, instead of the eccentric assembly, the bearings are made with filling slots, notches, or gaps, through which the balls may be inserted by elastic deformation of the races. These gaps do not extend right to the bottom of the groove, so that when the bearing is operating under light purely radial loads, the balls do not interfere with the edges of the gap, but with heavier radial loads or axial loads, the balls foul the gaps, causing noise and increase of stress, due to interruption of the elliptical contact area between race and ball.

Although the "gap"-type bearing will accommodate more balls than the "no-gap" type, owing to the effect of the notches, it is not certain how much of the increased theoretical capacity is obtained.

Ball journal bearings are made with varying amounts of diametric clearance, the tighter grades being used where the minimum amount of shake or play in the mechanism is necessary. Greater amounts of slackness are used to allow for

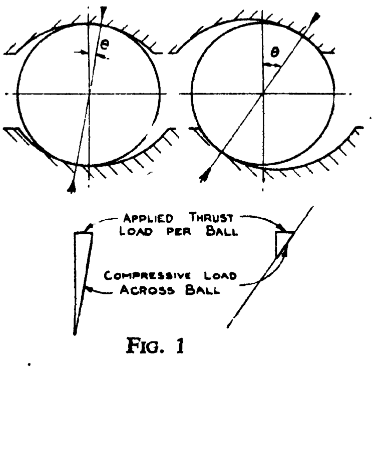

Fig. 1

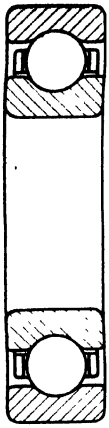
FIG. 2

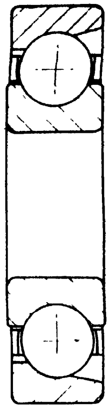
FIG. 3

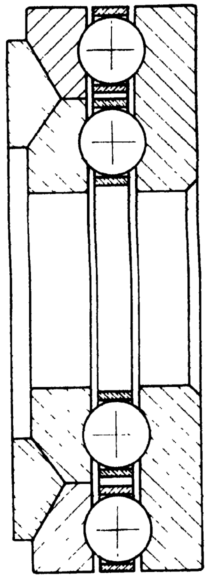
FIG. 4

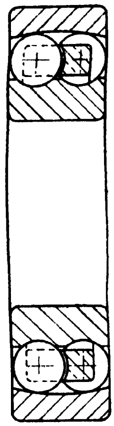
FIG. 5

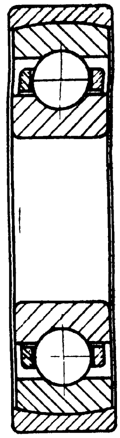
FIG. 6

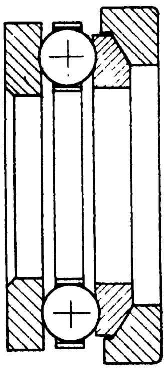
FIG. 7

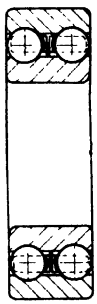
FIG. 8

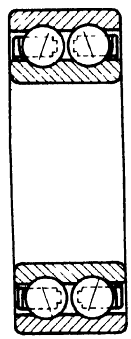
FIG. 9

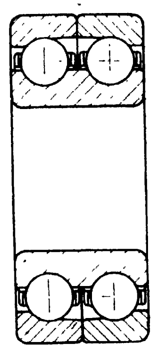
FIG. 10

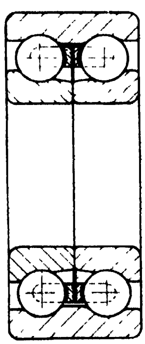
FIG. 11

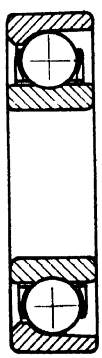
FIG. 12

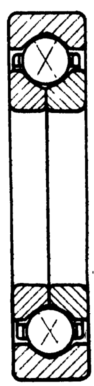
FIG. 13

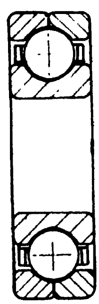
FIG. 14

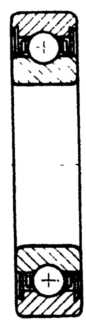
FIG. 15

deformation of the races due to interference fits on their seatings, to accommodate temperature gradients across the bearing, and to increase axial-load capacity. Under purely radial load, the balls contact right at the bottom of the tracks on a plane at right angles to the shaft centre, but under axial load the contacts move round at an angle to this plane. Increasing this contact angle reduces the load on individual balls caused by a given axial load applied to the bearing (Fig. 1).

Angular Contact Bearing (Fig. 3)

This is a modification of the single-row bearing, in which the contact angle has been made very large. The bearing has a deep lip on one side of the outer race to accommodate the large contact angle of the balls, but the other lip is cut away so that the outer race can be assembled by springing it over the inner race, cage, and balls. The shoulder on the cut-away side of the track is deep enough to keep the bearing together as a unit, but is not deep enough to withstand appreciable axial load towards it. The bearing is therefore only suitable for radial load, axial load in one direction, or combinations of the two.

The contact angle varies with different makes of bearing, but if the bearing is mounted singly, it must have sufficient axial load to maintain the balls at the designed contact angle. If the axial load is too small in proportion to the radial load, the balls will roll towards the bottom of the track and resultant radial movement of the bearing may be excessive.

Thrust Bearing

For purely axial load, the bearing shown in Fig. 30 is used. In this type, the balls make contact across axes which are in line with the shaft centre and the direction of load. It is completely unsuitable for carrying any radial load.

At one time, this pattern was the only one used extensively for carrying axial loads, and it is still the most suitable bearing for heavy axial loads at low speed or where the deflection under load has to be kept to a minimum.

At high speeds, centrifugal and gyroscopic action on the balls may cause trouble, and therefore the angular contact bearing is becoming more and more popular owing to its greater ability for dealing with these forces and for carrying radial components in addition to the axial load.

Double-row Self-aligning Ball Journal Bearing

Successful operation of the first three types depends upon accurate alignment of the races, and where the alignment is doubtful, it is necessary to provide some compensation. One method is the type (shown in Fig. 5) in which the outer track is formed as part of a sphere. With this pattern, a large number of balls can be fitted, but the form of the outer track is much less suitable for carrying heavy loads than the rigid patterns of Figs. 2 and 3, which have tracks with curvature conforming very closely to the curvature of the ball.

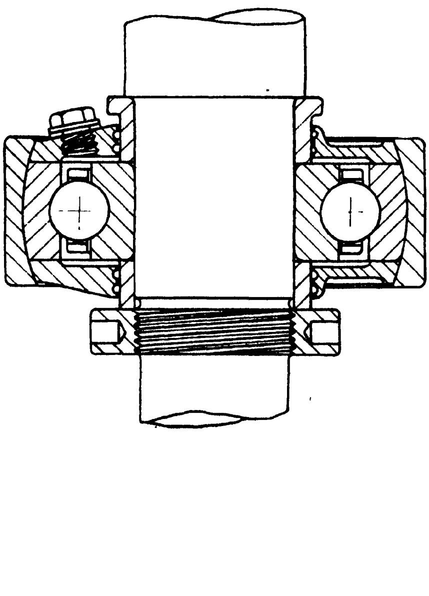

FIG. 16

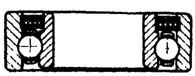

FIG. 17

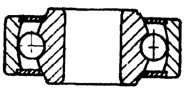

FIG. 18

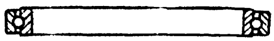

FIG. 19

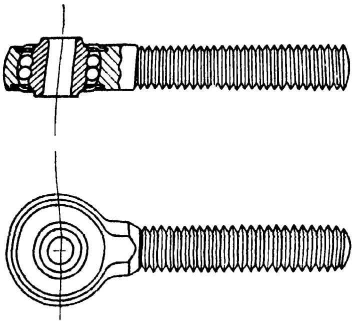

FIG. 20

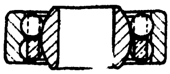

FIG. 21

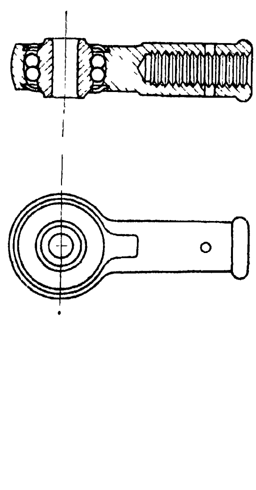

FIG. 22

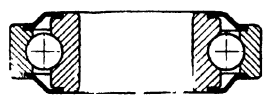

FIG. 23

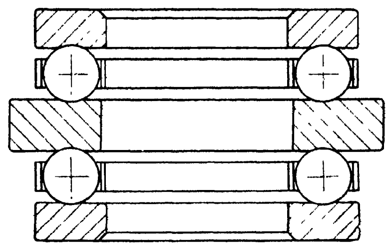

FIG. 24

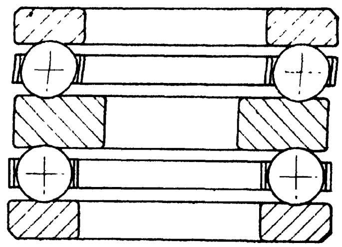

FIG. 25

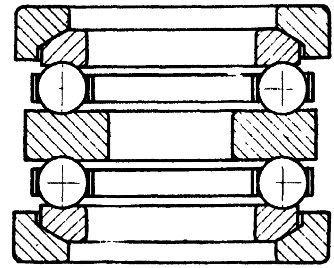

FIG. 26

deformation of the races due to interference fits on their seatings, to accommodate temperature gradients across the bearing, and to increase axial-load capacity. Under purely radial load, the balls contact right at the bottom of the tracks on a plane at right angles to the shaft centre, but under axial load the contacts move round at an angle to this plane. Increasing this contact angle reduces the load on individual balls caused by a given axial load applied to the bearing (Fig. 1).

Angular Contact Bearing (Fig. 3)

This is a modification of the single-row bearing, in which the contact angle has been made very large. The bearing has a deep lip on one side of the outer race to accommodate the large contact angle of the balls, but the other lip is cut away so that the outer race can be assembled by springing it over the inner race, cage, and balls. The shoulder on the cut-away side of the track is deep enough to keep the bearing together as a unit, but is not deep enough to withstand appreciable axial load towards it. The bearing is therefore only suitable for radial load, axial load in one direction, or combinations of the two.

The contact angle varies with different makes of bearing, but if the bearing is mounted singly, it must have sufficient axial load to maintain the balls at the designed contact angle. If the axial load is too small in proportion to the radial load, the balls will roll towards the bottom of the track and resultant radial movement of the bearing may be excessive.

Thrust Bearing

For purely axial load, the bearing shown in Fig. 30 is used. In this type, the balls make contact across axes which are in line with the shaft centre and the direction of load. It is completely unsuitable for carrying any radial load.

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Double-row Self-aligning Ball Journal Bearing

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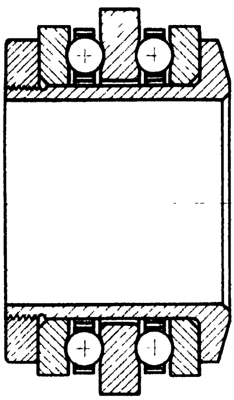

FIG. 27

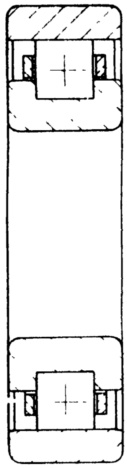

FIG. 28

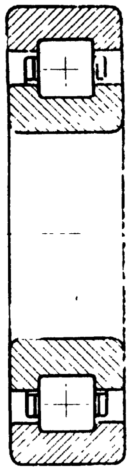

FIG. 29

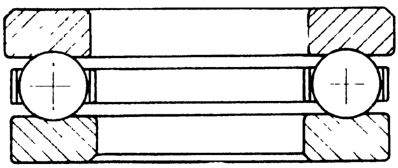

FIG. 30

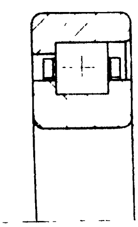

FIG. 31

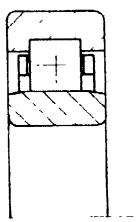

FIG. 32

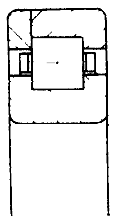

FIG. 33

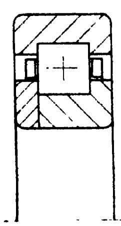

FIG. 34

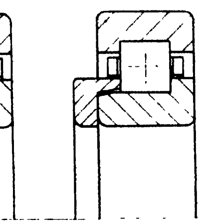

FIG. 35

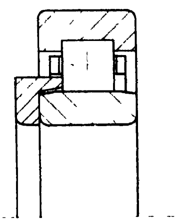

FIG. 36

It is made with one race split, either the inner race as in Fig. 13, or the outer race as in Fig. 14. Both the inner and outer tracks are formed with a double curvature, and under axial load, or combination of loads in which the axial load is the greater, the balls make contact with only one side of the inner and the opposite side of the outer track. If radial loads in excess of the axial are applied to this type of bearing, they are liable to make contact at both sides of inner and outer races simultaneously, and under these conditions very severe skidding takes place between the balls and the tracks.

Single-row Self-aligning Bearing with Spherical Covers (Fig. 16)

In this type of bearing, the outside diameters of the covers are formed as parts of the same sphere as the outside diameter of the outer race, and they can therefore follow the outer race as it swivels in the housing. By this means, the fine clearance between the bores of the covers and the shoulders is maintained, thus ensuring efficient protection of the bearing.

Single-row Rigid Bearing with Shields

A single-row rigid bearing with shields is shown in Fig. 15.

The shields will keep out some foreign matter and retain grease, but do not provide adequate protection against dusty or wet conditions and are not oiltight.

Single-row Rigid Bearing with Felt Seals

Fig. 17 shows a single-row rigid bearing with felt seals.

The felt which makes contact with both races provides more protection than the simple shield of Fig. 15, but the rubbing contact of the felt causes a definite frictional resistance.

Single-row Self-aligning Bearing with Seals (Fig. 18)

This is a special type which is largely used on aircraft controls.

Figs. 19–23 are further types which have been used on aircraft controls.

Double-thrust Bearings

These are used to carry axial load in both directions, and they can be supplied in the rigid patterns as in Figs. 24 and 25, or the self-aligning type in Fig. 26. They can be supplied complete with sleeve and nut (Fig. 27), when the user prefers the bearing manufacturer to carry out the necessary adjustment of the end-locating faces. With the types shown in Figs. 24–26 this adjustment must be carried out by the user, taking care that the bearings are not subjected to excessive preload.

Double-row Thrust Bearing (Fig. 4)

This is made for carrying loads beyond the capacity of a single-row thrust bearing. The two lower races rest on the inclined faces of an elastic ring, these inclined faces having angles such that the elastic ring is in equilibrium when the loads on the two rows of balls are proportional to their capacities, the outer row, of course, having more balls than the inner row. Alternatively, the split lower race may rest on a resilient washer of material such as lead or linoleum.

Parallel Roller Bearings

These are made with the designs shown in Figs 28, 29, and 31–38, with cylindrical rollers having their diameter and length equal. Rollers of this shape can be made with very great accuracy, and consequently bearings fitted with them are able to carry very much heavier loads than the equivalent size ball bearing. The rollers are guided by accurately ground lips and spaced by suitable cages or separators, except in the type shown in Fig. 38, which is made with a full row of rollers. The other patterns are also sometimes supplied with a full row of rollers, but usually only in the case of moderate-speed applications, when heavy load necessitates the extra number of rollers.

In bearings as in Fig. 28, the rollers are guided by lips on the inner race and the outer race has no lips. Fig. 32 has rollers guided by lips in the outer race,

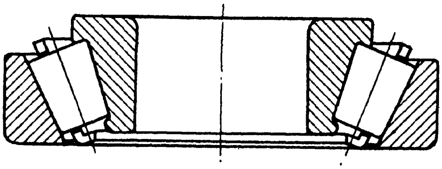

Fig. 43

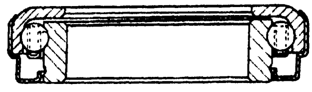

Fig. 50

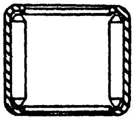

Fig. 42

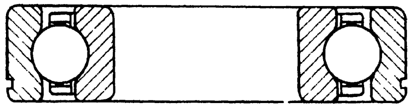

Fig. 48

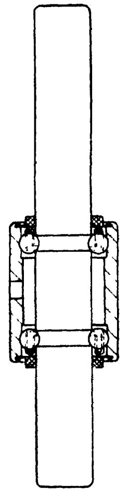

Fig. 49

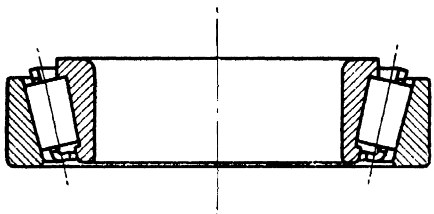

Fig. 41

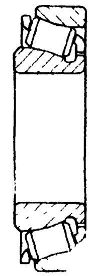

Fig. 47

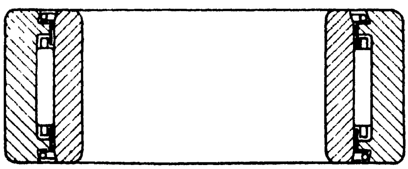

Fig. 40

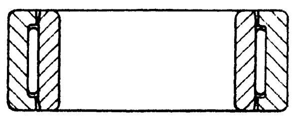

Fig. 39

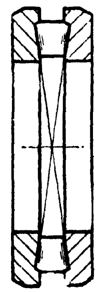

Fig. 45

Fig. 46

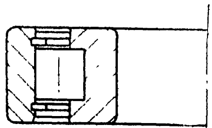

Fig. 38

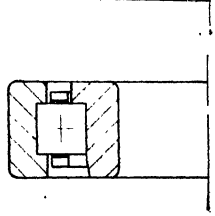

Fig. 37

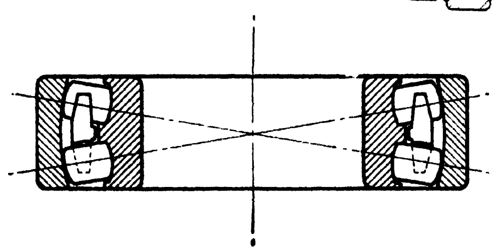

Fig. 44

with no lips on the inner race. With both these types, it is necessary to hold both races endways and to provide axial location of the shaft elsewhere.

Other patterns have two lips on one race and one or two lips on the other race, and these lips are capable of providing end location for the shaft. They are not recommended for continuous axial load of any magnitude, but will deal with quite heavy intermittent loads, and have been used with success to deal with the heavy axial loads which are set up intermittently in such applications as hubs of heavy commercial vehicles and tram-car axle boxes.

Rollers having lengths slightly greater than their diameter are also considerably used and, in recent years, improved manufacturing techniques enabling very long rollers to be produced accurately have caused the so-called "Needle Roller Bearings" to become popular. Types of this bearing are shown in Figs. 39, 40, and 42. The needle-type bearing is specially suitable for oscillating motions of very small amplitudes, as for such applications it is preferable for the arc of contact of one roller on the track to overlap that of the next roller. The needle roller is more susceptible than the shorter roller to any lack of alignment.

Taper Roller Bearings

In these bearings, the rolling element is the frustrum of a cone. For these rolling elements to maintain true rolling motion it is necessary for the apices of the cones, of which inner and outer tracks and rollers are parts, to meet at a common point on the axis of the bearing. The pressures on the sides of the conical roller have an unbalanced component pushing the roller towards its large end, and this component must be balanced by pressure between the large end of the roller and a guiding lip on the inner or outer race.

It is very difficult to provide a surface of contact between these faces. In fact, the only way of doing this is to make the end of the roller and the surface of the lip spherical surfaces of identical radii, described from the common apex of the cones. Any other form will give either a single-point or radial-line contact at the centre of the adjacent surfaces or two points at the ends of these surfaces. The former will have lower rubbing speeds, the latter will have higher rubbing speeds, but will help to maintain the axis of the roller in its correct position relative to the tracks.

The taper roller bearing is made with various track angles to accommodate different combinations of radial and axial load, Fig. 41 being most suitable for mainly radial loads, Fig. 43 for combined loads with a high proportion of axial load, and Fig. 45 for purely axial loads.

Double-row Self-aligning (or "Barrel") Roller Bearing (Fig. 44)

This is a compromise between the ball and roller bearing. The outer track is made spherical to provide for errors of alignment. The rollers are made with a radius smaller than the radius of the spherical outer track. The contour of the inner track conforms very closely to that of the roller. The barrel roller will

carry more load than a ball of equal diameter, but less than a parallel roller of equivalent diameter and length.

The barrel roller is sometimes made symmetrical, but more often with its maximum diameter displaced towards one end, so that, like the taper roller, it has a load component holding the larger end in contact with the guiding lip. A very similar type of roller is used for the thrust bearing shown in Fig. 46.

Roller Bearing with Spherical Inner Track

Fig. 47 shows a roller bearing with a spherical inner track. The spherical surface of the inner track accommodates lack of alignment. The shape of the tracks does not permit true rolling motion.

Recent Developments of Ball Bearings

Three types of ball bearing which have been developed in recent years are shown in Figs. 48, 49, and 50. The bearing shown in Fig. 48 is similar to Fig. 1, but has in the outer race a groove into which a spring ring can be snapped. In some applications this simplifies the mounting. The double-row bearing shown in Fig. 49 is used on cars to carry the water pump and fan, which are attached one at each end of the spindle. The single-row ball bearing of Fig. 50 is specially designed to operate the clutch release on cars.

Dimensions

The overall dimensions of many series of ball and parallel roller bearings are controlled by National or International standards. The first British Standard Specification for bearings was No. 292-1927, so the anti-friction bearing industry was very early in the field with the interchangeable standard components, the use of which forms the basis for much of the modern mass-production technique. Many of the sizes included in No. 292-1927 had been in current use for nearly twenty years.

Specification No. 292-1927 includes both inch- and metric-dimensioned bearings. The inch sizes are standardised only in Britain, but the metric series, with minor variations, are in current use almost throughout the world.

The external dimensions being fixed, improvement in bearing design is confined to internal construction, material and its treatment, and development of new types, but the range of sizes is constantly being increased, both towards very large and very small bearings.

As the dimensions of these standard series are very widely publicised, it is not intended to fill this work with tables cut from B.S. No. 292-1927 or a maker's catalogue. Data on the internal design and theory of bearings is also not included, as these are highly specialised subjects of interest to bearing makers and designers rather than bearing users.

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E. G. L.

HAND-HELD OR PORTABLE POWER TOOLS

FIG. 1.—USING $\frac{1}{4}$-IN. "HOLGUN" DRILL IN PRE-FAB. CONSTRUCTION

DURING the last ten years, hand-held or portable power tools, electrically driven, have become widely popular as a means of speeding up a multitude of jobs erstwhile performed by hand tools.

Most of the types of these tools we know so well to-day were in existence prior to 1939, although certain new ones have been introduced during the last two or three years; but the scope of many of these tools increased as and when they were applied to solve the problems of more and more industries.

DRILLS

Much development has taken place in the design of drills since the early ill-balanced models, with their heavy motors, were made, for now there is available a range of types and speeds to suit the individual needs of every job.

The small $\frac{1}{4}$-in. drill of to-day has abundant power, is ruggedly constructed in light aluminium alloy, has a pistol grip, and its motor, universally wound, is geared to a speed and torque that is known to be satisfactory for drilling holes up to $\frac{1}{4}$ in. diameter. As the size of hole to be drilled increases, the speed of the drill drops, while the torque also increases, thus maintaining the cutting speed of the machine. With a very large drill the no-load speed is generally round about 250 r.p.m., yet the torque developed by the triple reduction-gear train is so high that for holes of 1 in. diameter in steel it often takes two men to control the drilling, an almost impossible task by hand.

All the universal motors built into electric tools have a free speed of over 13,000 r.p.m., and it is consequently necessary to gear them down to a speed suitable for the size of hole required.

Capacity Rating

The capacity rating of all electric drills is usually given in steel, which means that the drill is powered to function at maximum efficiency in steel to the diameter of its capacity rating, i.e. a $\frac{1}{2}$-in. electric drill will cut efficiently holes in steel up to $\frac{1}{2}$ in. in diameter.

This capacity rating in steel dates from the early days when drills were thought to be engineers' tools and, although they still are, many other trades have adopted their use as standard practice for drilling in softer materials, so that this capacity rating does not always apply. When drilling in hardwood, the capacity rating can be doubled, so that a $\frac{1}{2}$-in. drill can be successfully used to drill holes of 1 in. diameter.

Repetition Work

To adapt the drill to repetition work, or to make it suitable for drilling light components, it can be fitted into a drill stand, of which there are several mountings—a bench drill stand for bench work, a similar stand with tripod legs, commonly called a pedestal stand, or one fitted with a wall mounting, termed a post drill stand. All three have a lever feed similar to a drill press, and can be used for accurate mass-production drilling. There is also a horizontal drill stand for mounting $\frac{1}{4}$–$\frac{3}{8}$-in. end handle drills to adapt them to light grinding, wire brushing, or occasional buffing.

Heavy Work

For heavy work, such as large castings, a favourite mounting for one or two drills is the sliding arm. This piece of equipment consists of a heavy base pedestal in which is held a column, adjustable for height, carrying an arm that slides on roller bearings. At the ends of this arm, drill-stand columns and brackets are fixed to hold the drills, making it possible to swing them a full 360° and at the same time to move the slide backwards or forwards to any given position within the orbit of the equipment.

Hole Saws

Another useful accessory to the drill is the hole saw. Held on a mandrel fitted into the chuck of the drill, hole saws will cut clean round holes in any material that can be cut by a hacksaw. They are made in three different grades: coarse tooth for cutting in coarse-grain materials such as cast iron, wood, fibre-board and similar materials; fine-tooth for cutting in steel and other fine-grain materials, and high-speed for work on stainless or chrome steel and other hard alloys. Sizes vary from $\frac{3}{4}$ in. to 4 in., in sixteenths up to 2 in., and then in eighths up to 4 in. The best speeds for cutting with hole saws are to be found in drills with $\frac{5}{16}$-in., $\frac{3}{8}$-in., and $\frac{1}{2}$-in. capacities.

BENCH AND PORTABLE GRINDERS

Although not exactly portable, all models, except the very largest, are transportable, and can be placed either on bench or pedestal at convenient points in any workshop. They have superseded the old grindstone for tool sharpening and the file for many jobs that were once carried out laboriously by hand.

FIG. 2.—GRINDING ROUGH EDGE OF ANGLE-IRON ON BENCH GRINDER

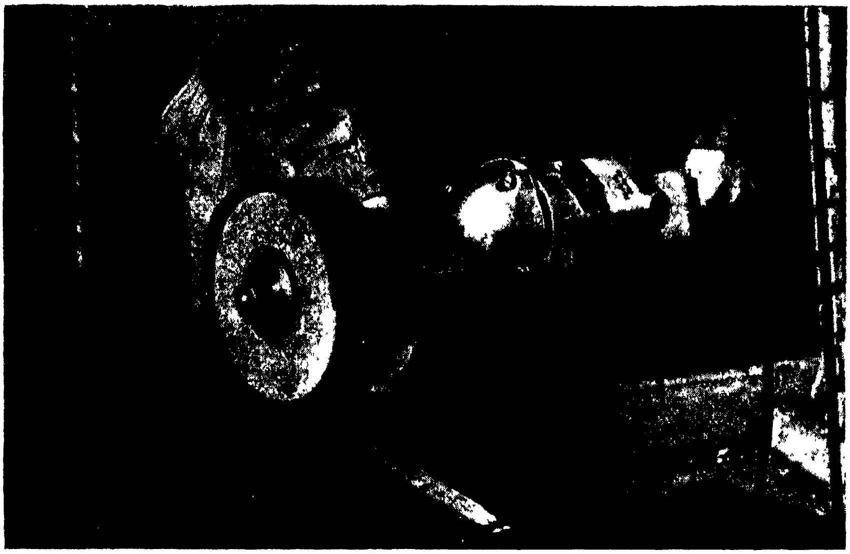

FIG. 3.—SMOOTHING WITH PORTABLE GRINDER EDGE OF STEEL PLATE WHICH HAS BEEN CUT BY OXY-ACETYLENE

Bench Grinders

The popular smaller bench grinders with 6-in. wheels are usually found in machine shops, assembly plants, and maintenance departments, for tool sharpening, light grinding, and light wire brushing; while the larger models with 8-in. and 10-in. wheels are used for heavy scurfing, grinding, buffing, and wire brushing where more power is required. These larger models are usually fitted with exhaust outlets that can be connected to existing exhaust systems. Tool rests and spark shields are standard equipment on the larger machines, and glass eyeshields can be provided where extra precaution against flying particles is thought necessary.

Portable Grinders

If components are too heavy to be taken to a stationary grinder, the portable grinder comes into its own. With a thumb-controlled switch in the handle, and a convenient grip for the second hand, this type of grinder is easy to operate without undue fatigue. For grinding flashes from raw castings and new welds, or for grinding the heads from rivets, this tool is ideal. The wheel guard, which at all times covers half of the wheel edge, is adjustable to any position by slackening the retaining bolts.

The smaller types of grinder with up to 3-in. wheels can be conveniently transformed into die grinders for internal grinding, profiling, and similar

operations. Similarly, a die grinder can be used for light external grinding, and with the addition of a tool-post holder serves a useful purpose for grinding operations on a lathe.

SCREWDRIVERS AND WRENCHES

Although not so universal in application, these tools provide a fast sure method of driving screws of all kinds, running and unrunning nuts, and, with special chucks, setting studs. Their action is somewhat different from that of a drill, inasmuch as the screwdriver is fitted with a clutch mechanism to prevent burring of the screw heads.

Types of Clutch

The most widely used type of clutch is positive in action, usually a dog or pin type, with the teeth backed off to allow it to slip when the screw or nut has been driven home. Other designs of clutch are built into some models where a variety of tensions are required for different grades of work. These are adjustable to predetermined tension, so that the clutch will slip at the given setting. When driving very small screws, the adjustable clutch is invaluable for maintaining the unmarred head of the screw and for driving them to the same consistent tension.

Both these kinds of screwdriver clutches are spring loaded, allowing the bits or socket wrenches to idle until pressure is applied to machines, thus engaging them.

Method of Control

Most screwdrivers are controlled by an end handle for ease of operation in either the vertical or horizontal position. There is, however, the centre-drive type, which can be suspended over work benches where repetition is required in mass production. Instead of the trigger-type switch, centre-drive screwdrivers are usually fitted with a tumbler or paddle switch that is more convenient when grasping the tool round the body.

Nut Runners and Tappers

Larger screwdrivers, commonly called nut runners, are built like large drills with two side handles for easy control. They have been recently adopted for railway track maintenance, the power being fed to them by petrol electric generators. It is also common practice for nut runners to be used in railway wagon repair shops. Both nut runners and the larger screwdrivers can be fitted with reversing switches.

In this class of tool we can perhaps admit the portable electric tapper. It functions in a similar way, having a special tap-holding chuck. Instead of a clutch, it is designed with a mechanism that drives the tap under pressure; but when the pressure is released, the reversing action backs the tap out at high speed.

FIG. 4.—DRIVING WOOD SCREWS IN BUS BODY CONSTRUCTION WITH BLACK & DECKER NO. 14 SCREWDRIVER

FIG. 5.—NUT RUNNING ON TRUCK BODY CONSTRUCTION WITH BLACK & DECKER NO. 14 SCREWDRIVER

SHEET-METAL CUTTING

Sheet-metal fabrication is a field in which the electric tool has found its own particular niche. The power guillotine is not enough, although none can deny its usefulness. When special shapes are required, it becomes a matter of choice between the use of snips or a portable tool.

Shear and Nibbler

Both the portable electric shear and the electric nibbler will cut to curved or irregular lines with ease and accuracy. Speed is constant, whether cutting to template or to a given line, and where quantities are not sufficient for special blanking tools, their usefulness is beyond measure. It is necessary to adjust the gap between the blades for varying thicknesses of work when using an electric

shear, but this feature makes it possible to use the tool for cutting many other sheet materials, such as fibre-board, leather, leatheroid, and thin plywood.

SANDERS AND POLISHERS

The electric sander is a most useful and versatile tool. Of the two most popular types, let us first of all take the disc sander that has an angle head fitted with a flexible rubber pad on which the sanding discs are fixed.

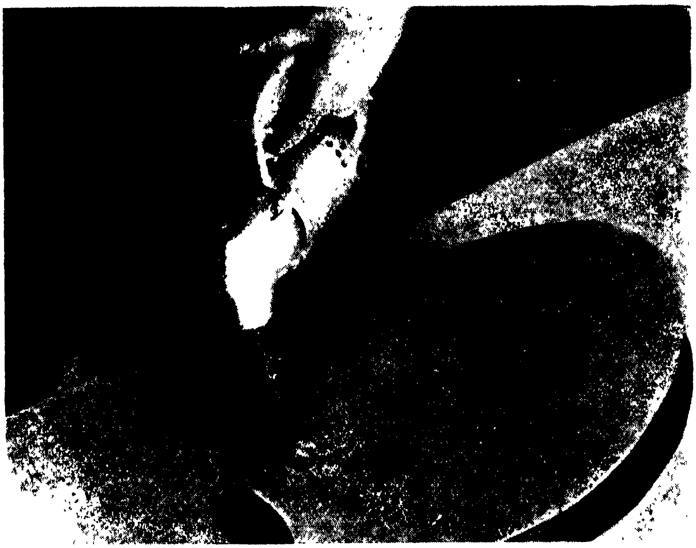

FIG. 6.—POCKET CUTTING IN GALVANISED SHEET WITH 16-GAUGE SHEAR

Disc Sander

It has a rotary action, but it must be noted that the entire surface of the disc does not come in contact with the work all at once. The correct working position is to have approximately two-thirds of the outer radius of the disc flat on the work at any one given time. This gives, not only a better control of the tool, but prevents the clamp washer, holding the disc in position, from damaging the work.

Sanding discs, similar to glass paper or emery cloth, are made in several types and many grits, from coarse to fine. Those suitable for metal are close in texture, while for wood or paint removing an open-grain disc is necessary. Such tools are eminently suitable for sanding metal or wood, de-rusting, paint removing, de-scaling, and to prepare surfaces for the application of paint.

De-rusting and Grinding Applications

By removing the rubber pad and disc, then threading on to the spindle a cup wire brush, it is possible to obtain a very satisfactory rotary wire brush

FIG. 7.—CLEANING WELDED EDGE OF CAR WING WITH DISC SANDER BEFORE REPAINTING

action that in some cases is more suitable for de-rusting. The scope of the disc sander is increased even more by the addition of a cup or saucer grinding wheel, which turns it into a right-angle portable grinder.

Planer Head Attachment

There is one more accessory that can be fitted to the versatile rotary sander—the planer head. This ingenious device is fitted with three detachable blades that will remove a considerable quantity of wood in a very short space of time. Two types are made—the flat type and the gouging type, but neither is designed for finished work. Both are suitable only for removing a surplus amount of material before attempting to finish.

Belt Sanders and Portable Polishers

The belt sander is equally popular for woodworking, although it is not so versatile in application. A continuous belt electrically driven forms the abrasive action beneath the machine which is used very much like an ordinary wood plane. For flat surfaces in wood this type is ideal, and perhaps gives the best final finish. However, it is not nearly so efficient where the surface is curved.

A very similar tool in both appearance and use to the disc sander is the portable electric polisher. Designed primarily for car polishing, it has been adapted very widely for polishing and waxing woodwork. Having a flexible rubber pad similar to the disc sander, one uses lamb's-wool pads or bonnets,

shear, but this feature makes it possible to use the tool for cutting many other sheet materials, such as fibre-board, leather, leatheroid, and thin plywood.

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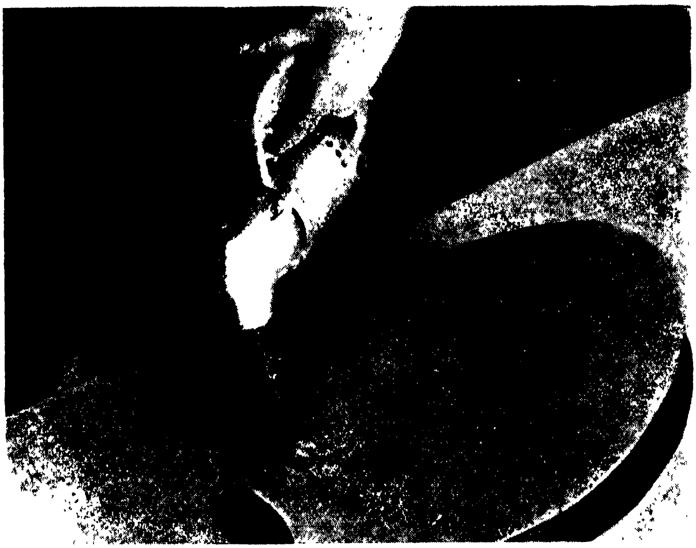

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To match the valve and seat the stone must, of course, be dressed to the same angle as that to which the valve has already been ground. The most common angles adopted by engine manufacturers are 30° and 45°, so stones are supplied as standard with two faces, one 30° and the other 45°. In order to obtain any other angle or to re-dress the stone, a dressing stand is provided, the mounted stone being placed on a dummy pilot so that a diamond-tipped dressing point, preset to the required angle, can be passed across the cutting face as the stone is rotated at normal speed by the driving unit.

FIG. 8.—GRINDING VALVES ON A VALVE MASTER REFACER

One of the most efficient types of seat grinder has built into it a vibrating action that lifts the stone once every revolution, clearing itself and the seat of all particles of abrasive and metal dust by centrifugal force, allowing an unimpeded cut to be taken.

Various sizes and grits of stone are procurable to cater for the different sizes of seat and the types of insert now being used.

Valve Stem, Tappet, and Rocker Grinding Attachment

An interesting accessory to this equipment is the micrometer valve stem, tappet, and rocker grinding attachment. Special provision is made on the valve refacer for its use at the opposite end of the grinding spindle to that which is used for valve grinding. A saucer wheel will accommodate the grinding of Ford valve stems and tappets to produce the correct tappet clearance when the valves

and seats have been ground. This same attachment will grind worn rocker arms for overhead-valve engines.

Other Tools

There are, of course, other portable electric tools, many of which have been specially designed for specific purposes. For instance, there are such tools as the electric saw, hammer, and plane, the mortising attachment to adapt the drill for mortising, and the electric blower. In its own particular field the electric saw is perhaps as versatile as the drill, for with a set of interchangeable blades it is possible to cut a wide variety of different materials—wood, coarse or fine cuts,

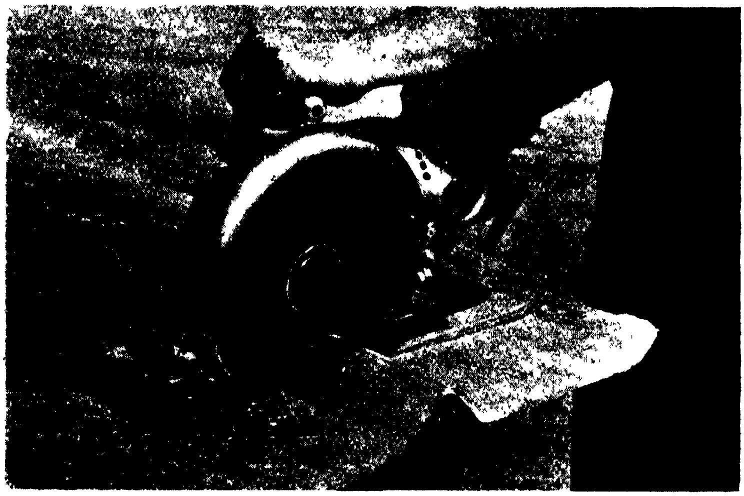

FIG. 9.—CUTTING CEMENT ASBESTOS SHEETING WITH "RIPSNORTER" SAW

some suitable even for immediate gluing, non-ferrous metals, in sheet, tube or light bar form, cast iron, gutters, water or fall pipes, bricks, tiles, cement asbestos, and all kinds of ceramics, natural stone, corrugated iron, and a host of other materials.

With the several sizes of electric hammer one can drill, chase, chip in concrete, brick or stone, prepare surfaces for rendering, break through or cut away existing brick or concrete, tamp concrete formes by vibration, and many other useful jobs.

Time and Motion Study

To illustrate the reasons why these powered hand tools have become so popular, let us take a look at the time and motion studies made by one manufacturer of portable electric tools (Figs. 10 and 11). The path of light left on the

photographic plate by the lamp attached to the operator's wrist records the effort needed to perform each operation, whether by hand or machine. It clearly indicates the fatigue element in each case in favour of the power-driven tool. Used in conjunction with the recorded times given beneath the illustrations, we have conclusive proof of the very considerable saving in time and effort gained by the introduction of these tools.

MANUFACTURING PROCESSES

The better-known makes are produced to-day in fairly large quantities which give rise to the need for modern efficient plant and methods. Constant inspection is given to tools and components as they pass from one stage to another, so that when packed ready for despatch the manufacturers have every confidence in the quality and performance of each and every tool.

Motor Windings

Motors are wound on specially designed machines that give neat tight armatures and fields; tests are made while these windings are in the white. They are dipped and baked, and when ground and skimmed a balancing operation takes place on a stroboscopic balancer, that not only decides the point at which the armature is out of balance, but indicates the extent of the defect. Correction of such faults ensures the smooth free running of the motor. Finally, all armatures are subjected to rigid flash and drop tests before they are passed for assembly into the complete tool.

Machined Parts

Machined parts are treated in much the same way, passing through an inspection department before being stored for subsequent issue to the assembly shops. Batteries of modern capstan lathes, automatics, and grinders turn out to the given limits of manufacture the thousands of component parts required to assemble one batch of tools. Gear cutters, hobbers, broaching machines, centreless grinders, multi-spindle drills, high-frequency hardening, all play their part in producing the finished product.

Flow systems of assembly with central conveyors have been adopted as standard, the subassemblies being fed to the main conveyor, where they are built into the complete tool.

Assembly Department

It is interesting to note that for many operations in the assembly department these manufacturers take their own medicine by applying the use of electric tools to speed up their own production methods. Small drills and screwdrivers are suspended above work benches, drills and reamers in bench stands are spotted at convenient points for quick access, while bench grinders are in constant demand for the sharpening of cutters, tool bits, and hand tools.

FIG. 10.—TIME AND MOTION STUDY OF CUTTING DURALUMIN SHEET

With a new hacksaw blade the operator is making an 8-in. cut in ⅛-in. thick duralumin sheet. Progress is slow and laborious, the effort being recorded by the tell-tale light on the research engineer's wrist.

Time taken—125 secs.

With the Black & Decker "Ripsnorter" saw, fitted with a non-ferrous metal-cutting blade, a fast easy cut is made in 9·5 secs.

Comparison—13 times faster by "Ripsnorter" saw—effort negligible.

FIG. 11.—TIME AND MOTION STUDY OF DRILLING IN MILD-STEEL PLATE

Using a wheel brace, the operator is drilling a ¼-in. hole in a piece of ⅜-in. thick mild-steel plate. Camera again catches the effort-wasting movement of the hand method.

Time taken—2 mins. 11 secs.

With the ¼-in. "Holgun," the effort is again negligible and the time required to drill the same-size hole is 27 secs. Speed is again constant on repeat operations.

Comparison—approximately 5 times faster by ¼-in. "Holgun."

Inspection Department

Once again the inspection department comes into the picture. Each tool is run for an hour or two so that any mechanical or electrical fault will immediately show itself. Each tool is again subjected to electrical tests, a speed test and, where necessary, chuck alignment.

MAINTENANCE

All portable tools should be checked periodically for frayed cables, worn-down carbon brushes not making proper contact with commutators, lack of grease in gearcases, and dirty motors.

Motors can also be caused to run hot and sluggish through the ventilation holes provided in the field case of each machine becoming clogged. It is essential that these holes are cleaned out periodically, preferably by compressed air.

Through constant use gearcase grease becomes dirty and useless as a lubricant. This should be changed from time to time, dependent upon the use to which the tool is put, always taking care not to fill the gearcase more than half full, as a surplus will be forced back into the motor, causing damage.

All electrical connections should be checked over periodically with particular emphasis on the earth connections; frayed leads or worn cables should be replaced immediately.

Where a number of similar tools are in use in the same plant, it is as well to have a maintenance system to provide for spare tools so that units can be withdrawn from the shops, replace with spares, and to maintain a periodic inspection of all units in turn. If the repair is a major one, do not attempt it unless you have guaranteed replacement parts available. Even then it is better to send the machine to a manufacturer's service station where specially trained engineers are competent to diagnose the trouble and to effect the necessary repair with factory-produced replacement parts.

Care of Tools

Electric tools should not be carried by their cables, nor should they be dragged from one work centre to another. This damages the more delicate parts of the machine.

Always connect the earth wire—don't court danger.

If you have lost the chuck key of an electric drill, don't use a hammer or any other heavy instrument to loosen it. A chuck is a precision-made part of the drill, and will give faulty alignment if treated in this way.

When you have finished with a tool, coil up the cable and place it out of the way of passing traffic. Trucks running over cables will damage them in no time.

Make sure that the accessories you use with these tools are in good condition. Blunt drill bits, for instance, will put an additional load on the drill, which is not only harmful to it, but will increase your operation time as well.

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M. W. B.

LATHES AND LATHEWORK

THE lathe is often spoken of as the "king of tools," as practically every kind of work which is carried out on other machine tools can also be done on the lathe, though not so expeditiously or simply as do the tools expressly designed for the work in question and that only. The lathe can also be regarded as the oldest form known of machining tool, as it is shown in ancient Egyptian records.

Lathes are generally divided into three distinct groups: (1) engine and tool-room lathes, (2) capstan and turret lathes, and (3) automatic lathes. The last two types are really only variations of the first type designed to carry out one or two special classes of work more efficiently than could be accomplished on the first types, but while this work could, if occasion called, be accomplished on the engine lathe albeit in a costly and somewhat inefficient manner, the general work of an engine lathe could not be carried out on the latter types. It will therefore be only necessary to describe the sliding, surfacing, and screw-cutting lathe, and a typical lathe is shown in Fig. 1. This is the forerunner of the modern lathe of this type, and will show how the modern lathe has been evolved.

I. THE SLIDING, SURFACING, AND SCREW-CUTTING LATHE

The figure is almost self-explanatory. The names of the parts are those normally used, and they will be adhered to throughout this section. It will be noticed that the lathe has various change wheels (*Z*), which are used for obtaining the various speed ratios between headstock spindle and lead screw required for screw-cutting. The belt (*a*) is for the purpose of transmitting to the saddle the power for the longitudinal and cross traverses. Both the above, and also the screw-cutting motions, can be reversed by lever (*Y*) in order to traverse away from the chuck or for left-hand screwing. These various feeds are controlled from the apron by the handles (*g*), (*h*), and (*j*), and are put out of action entirely by clutch (*b*), where hand operation only is desired. The back gears (*C*) are a simple two-speed device usually lowering all cone pulley speeds by about 9: 1, and can be readily disengaged by handle (*B*) and by locking the cone pulley (*F*) to the headstock spindle, when a direct drive is obtained. This arrangement is almost essential where work of any considerable diameter requires turning, as only by this method can it be run at its appropriate low speed while keeping the belt speed reasonably high to obtain the necessary power.

Sliding, Surfacing, and Screw-cutting

These terms refer to the power motions of the saddle. In the case of sliding, the saddle carrying the tool is moved along the bed by the keywayed shaft (*d*),

Key to lettering:

A, Backshaft. *B*, Handle for backgear engagement. *C*, Portion of backgear. *D*, Driving belt. *E*, Headstock. *F*. Cone driving pulley. *G*, Chuck. *H*, Saddle-locking screw. *I*, Turning tool. J, Toolholder screw. *K*, Toolpost, American pattern. *L*, Key for toolholder screw *J*. *M*, Toolholder. *N*, Top-slide traverse handle. *O*, Tailstock-barrel clamping handle. *P*, Tailstock. *Q*, Tailstock handwheel. *R*, Tailstock locking screw. S, Tailstock offsetting screw. *T*, Cross-traverse handle. *U*, Supporting legs. *V*, Faceplate. *W*, Driving or catch-plate. *X*, Spindle thrust. *Y*, Reversing handle. *Z*, Change wheels. *a*, Traverse driving belt. *b*, Traverse-shaft clutch. *c*, Lead screw. *d*, Traverse shaft. *e*, Traverse rack. *f*, Saddle-traverse handwheel. *g*, Longitudinal-traverse lock. *h*, Cross-traverse lock. *j*, Clasp-nut lever. *k*, Tray.

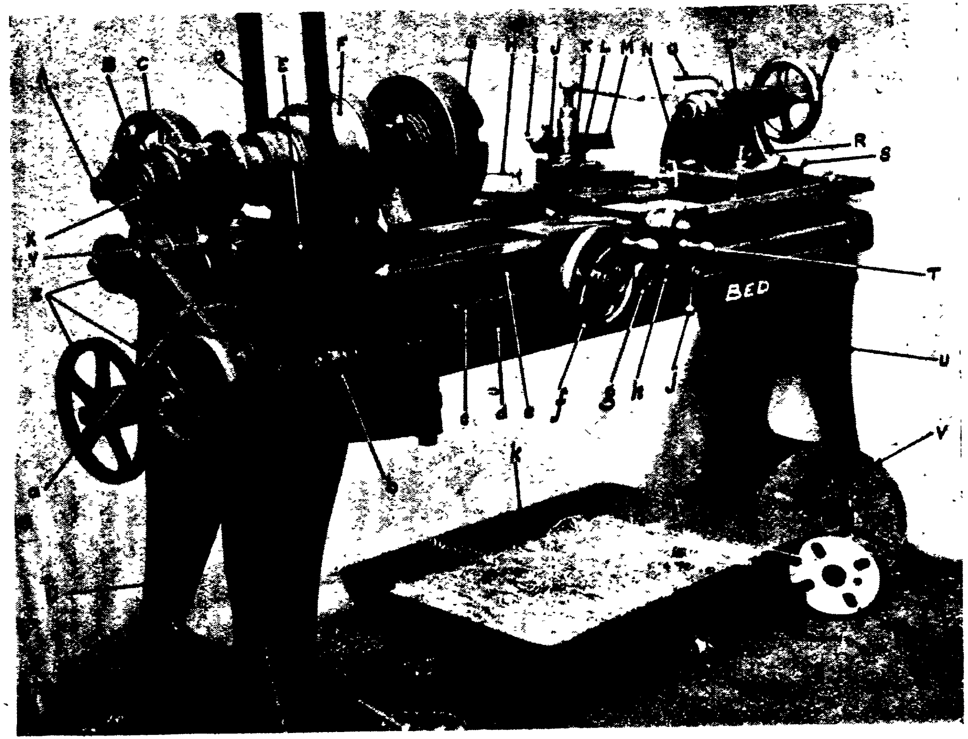


FIG. 1.—TYPICAL SLIDING, SURFACING, AND SCREW-CUTTING LATHE WITH AMERICAN-TYPE TOOLPOST

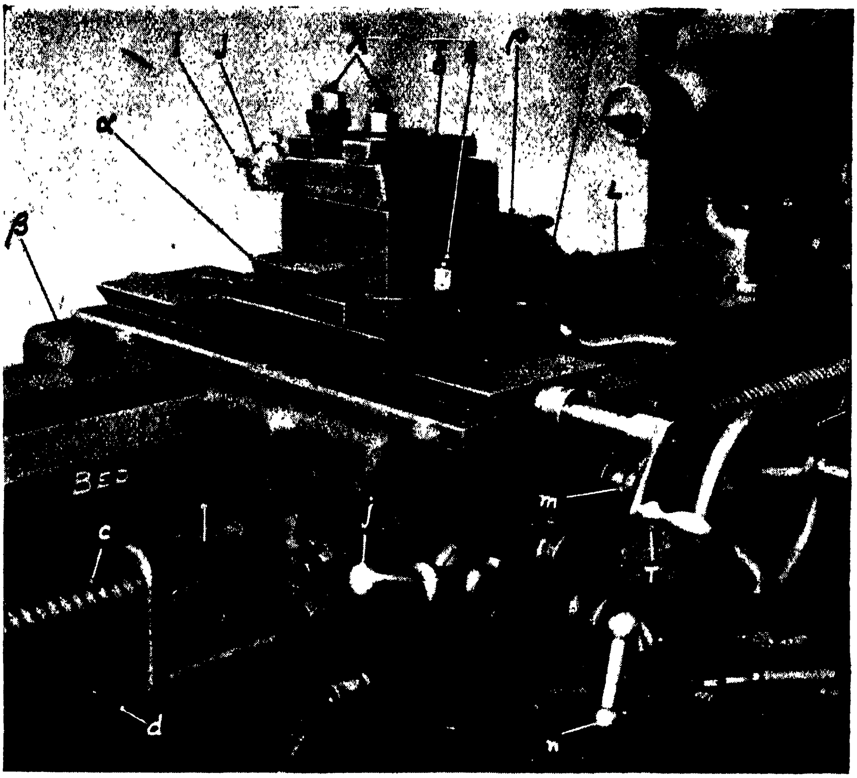


FIG. 2.—LATHE SADDLE WITH ENGLISH-TYPE TOOLPOST

n, Longitudinal-traverse lever. *m*, Cross-traverse lever. *t*, Cross-traverse handle. α, Cross-slide ways. β, Saddle top. λ, Toolpost T-bolts. δ, Toolpost clamps. ε, Top-slide lockscrews. ρ, Top-slide toolpost. Other references as in Fig. 1.

driving through the clutch and gearing in the apron (see Fig. 2) to the pinion gearing with rack (*e*). In the case of Fig. 2, the engagement and disengagement of this motion is obtained through a drop-worm box controlled by handle (*n*), while in the American lathe illustrated in Fig. 1 cone clutches are used.

Surfacing Motion

The surfacing motion on the English lathe (Fig. 2) is controlled by pull and push knob (*m*). In some lathes the lead screw and drive shaft are combined, the lead screw having a keyway down its entire length for sliding, while on smaller lathes the lead screw itself is the only method available for sliding; for this purpose a fine feed, say $\frac{1}{120}$ in., is necessary for fine tool finishing.

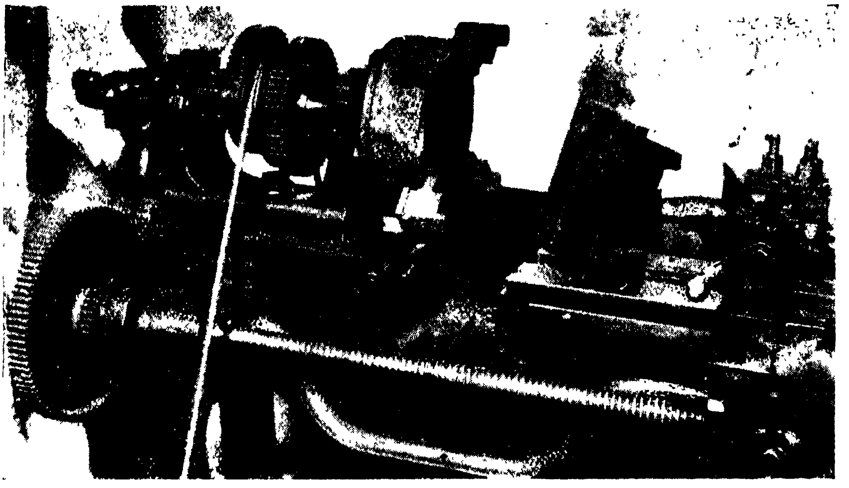


FIG. 3.—GAP LATHE

Types of Bed

Engine lathes are divided into two types, straight bed and gap bed. Fig. 3 shows a gap-bed lathe with the removable gap pieces standing on the bed to the right of the gap. In some cases the removable gap piece only partially bridges the gap and allows large-diameter chucks to be used if desired without removing the gap piece, and still allows the saddle to work close up to the chuck.

Screw-cutting Motion

All three lathes illustrated are capable of cutting screw threads of almost any pitch (i.e. number of threads in 1-in. length, sixteen in the case of $\frac{3}{8}$ Whitworth Standard). This is accomplished by means of the lead screws (*c*) in conjunction with the change wheels (*Z*). The screw is engaged by a split nut operated by handle (*j*), which, on being lifted, closes the nut on to the screw, thus moving the saddle along the bed. Various pitches of thread are cut with one lead screw by varying the number of teeth in the change wheels.

Motor-driven Lathes

The tendency in modern lathes is to abolish belt drives in favour of direct-coupled motor drives, and to arrange the changes of speed by a gear-changing device incorporated in the headstock. This will be seen in Fig. 4, where the electric motor is at the extreme left of the suds pan, driving on to the headstock by means of V-belts. The half-gap piece is shown fitted. In all modern lathes the lead screw is used for screw-cutting only to preserve its accuracy, the feed motions being taken off a separate shaft.

Fig. 6 is an example of a flat-bed lathe (no gap), and has separate screw-

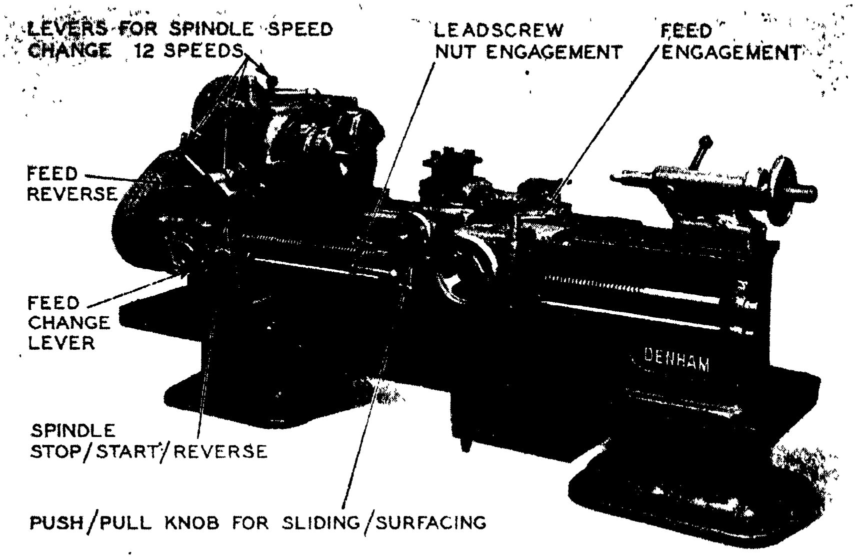


FIG. 4.—A 6¾-IN. CENTRE LATHE FITTED WITH A STANDARD 3-CHANGE GEARBOX AND TAPER TURNING ATTACHMENT (*Denham's Engineering Co., Ltd.*)

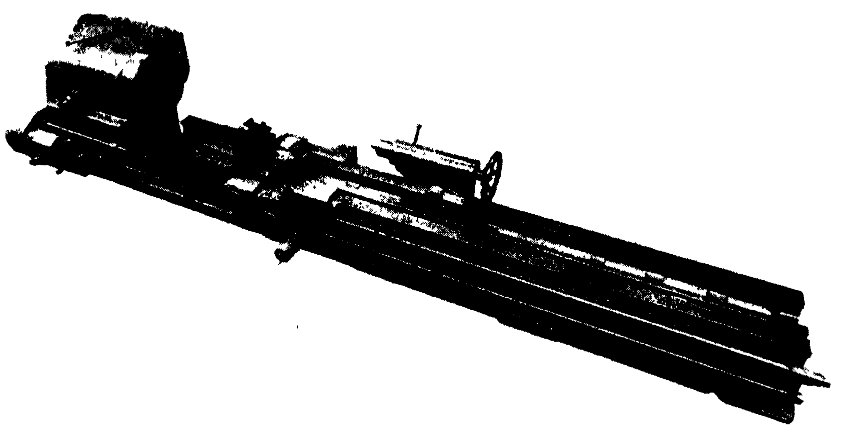


FIG. 5.—AN 18¾-IN. CENTRE LATHE ON A 34-FT. BED
Electric push-button control is fitted on the saddle for control of spindle.
(*Denham's Engineering Co., Ltd.*)

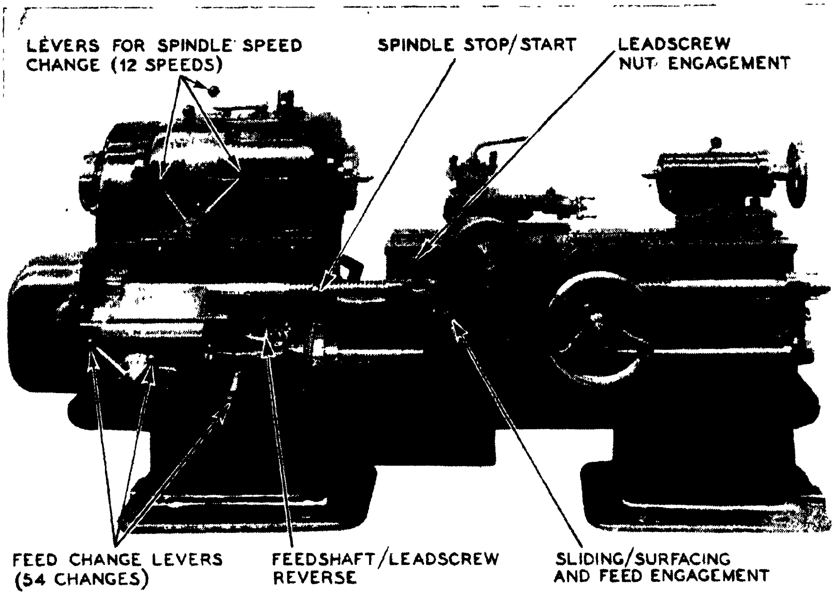


FIG. 6.—DENHAM "SUPERSPEED" LATHE WITH 6¾-IN. CENTRES AND FITTED WITH 54-CHANGE GEARBOX (*Denham's Engineering Co., Ltd.*)

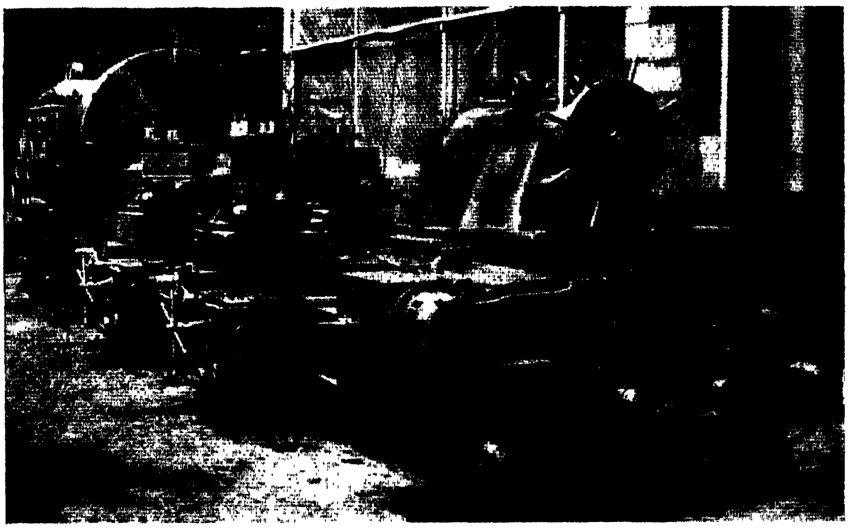


FIG. 7.—HARVEY HEAVY-DUTY LATHE WITH 36-IN. CENTRE (*Scottish Machine Tool Corporation, Ltd.*)

cutting and feed gearboxes. In this lathe the electric motor is bolted direct to the headstock and drives through V-belts.

Engine lathes are made up of very large sizes. Fig. 5 shows an 18¾-in. centre lathe with a 34-ft. bed; any length of bed can be supplied. The large lathes with long beds are generally fitted with two or more saddles for turning long shafts, and have push-button electric controls mounted on the saddles. The feed gears are on the aprons of the saddles for the cross slides. On these large tools separate-geared electric motors are usually fitted to traverse the loose headstock along the bed, which may be up to 675 ft. long, the headstock weighing up to 10 tons or so.

The lathe shown in Fig. 7 is one with a height of centres of 36 in., and it swings a diameter of 6 ft. over the bed. Its width between centres is 25 ft., but it will be noted that the end of the bed at the loosehead end is precision-machined and checked to take bed extensions for a greater length between centres if the need ever arises.

The speed changes of the spindle speeds, in the headstock, are all carried out by means of hardened and ground nickel-chrome gears, which slide upon heavy-splined shafts. The control of the speeds is operated by means of three handwheels seen on the side of the headstock. Normally, 16 spindle speeds are provided, ranging from 1 r.p.m. to 80 r.p.m. of the spindle, or from 1·5 r.p.m. to 120 r.p.m.

Each saddle of the lathe is a completely self-contained unit, with an independent set of feed and saddle controls, mounted, as will be seen in the illustration, on each saddle. Quick power-traverse by built-in electric motors is provided on each saddle, and also on the loosehead.

Electric control of the headstock is achieved by means of built-in flush-fitting push buttons which provide starting and running of the spindle in either direction. Inching buttons for both the forward and the reverse directions of spindle rotation are also provided.

TOOLS

Before proceeding to turning operations proper, it is necessary to consider the tools to be employed. These should be of a size to suit the lathe, and should, if possible, be made of air-hardening high-speed tool steel. Two broad divisions at once suggest themselves: solid tools, in which the shank and cutting edge are in one piece as in Fig. 8, and toolholder tools, which fit in the toolholders shown in Figs. 1 and 2. The actual cutting angles of these tools are, of course, the same for similar materials, so that in grinding the latter type due allowance must be made for the angle at which the toolholder is set. A toolholder, being mounted on a rocker, is conveniently adjustable for height of cutting edge, while a considerable saving is made in respect of material for the tools themselves.

The type of toolpost shown in Fig. 1 is known as the American type, while an English toolpost with clamps and nuts is shown in Fig. 2. Toolholders are available for both types, although the latter lends itself well to solid tools for heavy cutting.

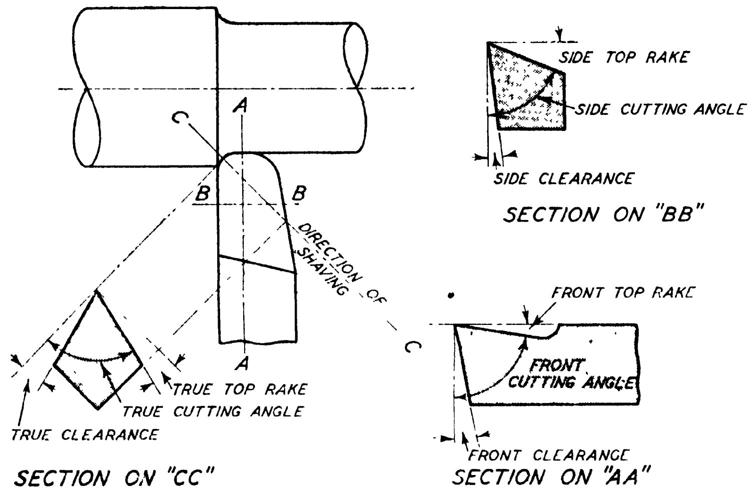


FIG. 8.—TERMS USED IN REFERENCE TO CUTTING ANGLES
(See Table I.)

Tool Angles

Tool angles vary according to the material to be cut, and it is almost impossible to obtain satisfactory results if the tools used are unsuitable.

Fig. 8 shows the fundamental angles of a cutting tool, also their relation to the work being operated on. Table I gives the value of these angles, which have been found suitable for varying materials.

Tool Forms

These angles can be applied to tools of the forms shown in Fig. 9:

(*a*) is a side-facing tool. (Made in R. and L. hand forms.)

(*b*) is a parting tool. (F.T. rake dispensed with. Top flat.)

TABLE I.—CUTTING ANGLES

	Gun-metal and Bronze	*Cast Iron*	*Steel*	*Wrought Iron*	*Brass*	*Cork*	*Fibre*	*Ebonite and Vul-canite*
F.T.R. (Front top rake) . . .	0°	10°	20°	22°	3°	—	65°	25°
S.T.R. (Side top rake) . . .	5°	9°	15°	25°	8°	—	65°	25°
F. clearance . .	5°	5°	8°	8°	7°	—	3°	7°
S. clearance . .	4°	4°	6°	4°	5°	3°	3°	8°
Cutting angle .	90°	80°	70°	68°	83°	Knife edge	25°	65°

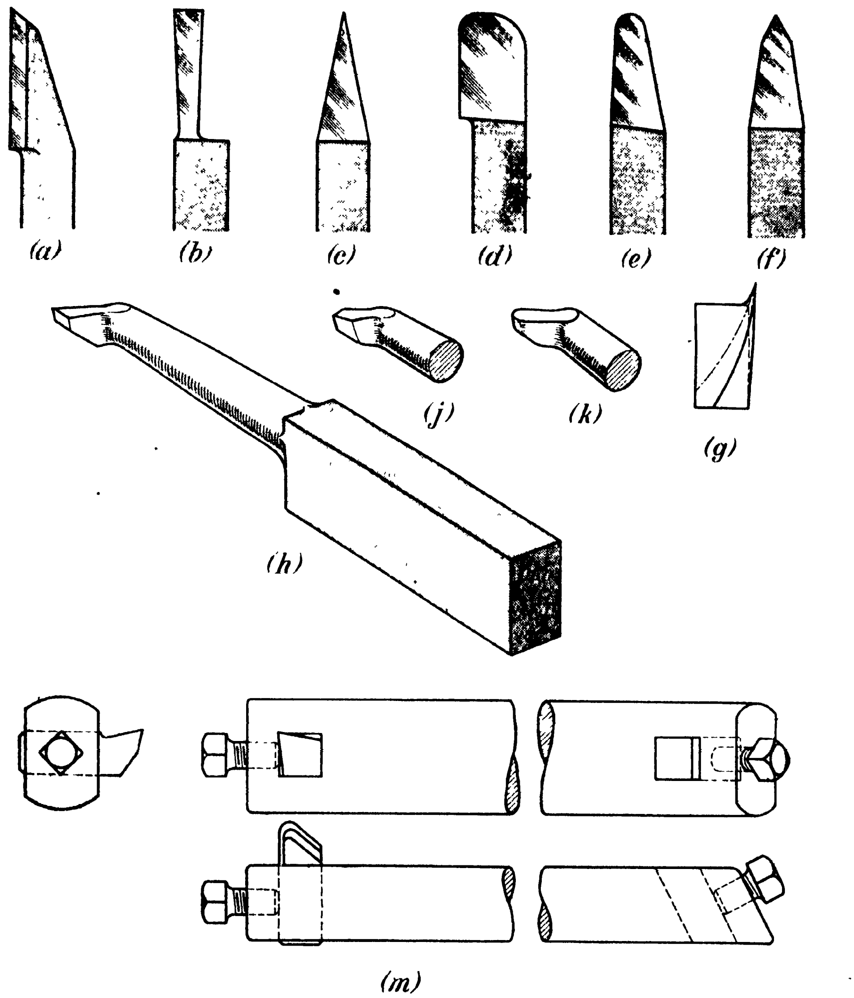


FIG. 9.—TYPES OF TURNING TOOLS

a, Facing tool. *b*, Parting tool. *c*, Diamond tool or right-hand and left-hand facing tool. *d*, Heavy rougher. *e*, Light rougher. *f*, V-thread tool. *g*, Tool for cork viewed from centre of work. Dot-dash line shows tool for fibre. *h*, Internal solid square threads. *j*, Internal V threads. *k*, Boring tool. *m*, Double-ended half-round boring toolholders.

(*c*) is a diamond or double-facing tool. The top of this tool is also flat.

(*d*) Heavy roughing tool. (Made for R. and L. hand cutting.)

(*e*) Light roughing tool. (Made for R. and L. hand cutting.)

(*f*) V-thread tool, slight radius on point to suit pitch of thread. Front top rake must not exceed 5°.

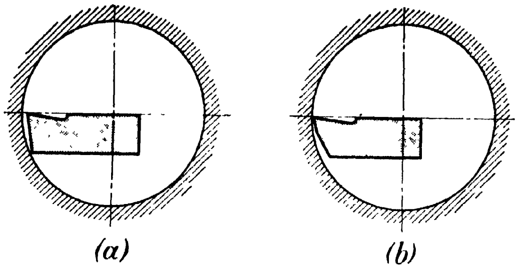


FIG. 10. — BORING TOOL

This shows why a tool used for boring requires a greater clearance on the heel. The standard clearance shown at (*a*) is insufficient.

(*g*) is a facing tool for cork and has a knife edge; a similar tool for turning fibre is shown by the dot-and-dash line. Both these tools are drawn as seen from the work.

Clearance Required for Boring Tools

Boring tools need a very much greater clearance angle than turning tools, the point being very clearly illustrated by Fig. 10: (*a*) shows an inserted cutter boring-tool bit having standard clearance ground on. This is insufficient, as fouling occurs at the bottom edge. In this case excessive clearance as shown in (*b*) is required, and all boring tools for small holes should have a very sharp front clearance.

Height of Tool to Work

The height of the tool in relation to the work exercises a considerable influence on the actual cutting angle; if above centre the cutting angle is decreased, and if the amount be sufficient, rubbing occurs. Should the point be below centre, the tool becomes more of a scraper and the cutting angle is increased (illustrated in Fig. 11). For taper turning by any method and for screw-cutting it is of the utmost importance that the cutting edge of the tool is exactly the same height as the work centre, and it is worth while going to some trouble to see that it is. In toolholders the angle of the tool must be correct when ready for use, so that any additional tilt of the holder must be allowed for.

The actual clearance required for boring tools depends solely on the size of the hole required.

Tipped Tools

Of late years tipped tools have come largely into use. These are called "tipped" because the cutting edges are formed by a small piece of carbide alloy or similar steel brazed or welded on to a suitable section of steel bar. As the special steel is very expensive, this construction greatly reduces the cost of the tools, and the special steel also enables much faster cutting speeds to be used on ordinary or extra hard or tough materials with infrequent stops for grinding. This grinding can only be carried out on special wheels, the ordinary emery or carborundum wheels not being suitable for the purpose.

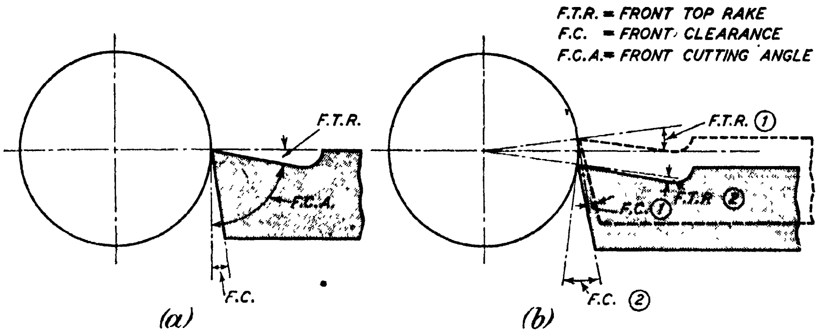


FIG. 11.—THIS SHOWS THE DIFFERENCES IN FRONT TOP RAKE AND FRONT CLEARANCE WHEN THE SAME TOOL IS SET ABOVE OR BELOW THE CENTRE OF THE WORK

When used under suitable conditions, these tools have an exceptionally long life between the grinds, with the result that tool setting and general maintenance costs are reduced. The wear-resisting surfaces also permit machining to very close limits; in addition, a very fine finish is obtained owing to the excellent surface of the tool itself.

The principal carbides now employed are tungsten carbide, molybdenum, titanium, and tantalum, and they are sold under the trade names of "Ardaloy," "Cutanit," "Escaloy," "Teco," "Wardite," and "Wimet."

Tungsten carbide can be used with advantage on materials such as cast iron, Bakelite, and fibre, which quickly break down the cutting edge of high-speed steel. It is not, however, entirely satisfactory for machinery steels, due to the affinity of the tungsten carbide to steel. The other materials machined were developed later and have overcome this tendency, and high-tensile steels may be cut with ease. Sets of tools can be bought ready tipped or sets of tips ready to be attached to suitable section holders.

Negative Rake

The use of carbide and similar alloy tools has led to an alteration in the rake of cutting tools for lathe and other machine tools. This is termed "negative rake."

If Fig. 11 is examined, the front top rake would not slope downwards from the point of the tool but upwards, and there would not be any top rake as the term is usually known, thus forming a negative rake. Used in the high-speed turning of hard, tough steel, this gives a longer life to the cutting edge and greater resistance to fracture.

SPEED OF WORKING

With regard to the work speeds, there is no hard-and-fast rule, but it may be taken roughly that brass is very fast, steel slower, and cast iron slower still. Typical r.p.m. on 2 in. diameter are as follows: 190, 135, and 75.

Screwing speeds are limited by the ability of the operator in engaging the clasp nut and cutting tool, and no risks should be run by trying to do this too fast, or a dig-in is a certainty.

HOW TO HOLD THE WORK

The work to be operated on may be held in a variety of ways, and a good workman is one who sees at once the correct way to do a job, taking into consideration subsequent operations.

Spindles

Spindles or studs may be centred, run on centres, and be driven by a carrier; or, if the retaining of the centre holes is unimportant, may have one end held in and driven by a concentric or independent chuck, as in Fig. 13. In this connection it should be noted that work held in a chuck can sustain far heavier cuts than work run on centres.

Bushes

Bushes or similar objects should be drilled in the chuck, and the hole reamed or tooled out to size. The outside should then be turned down as far as the jaws will permit, leaving, say, $\frac{1}{32}$ in. on the diameter, which, together with the thicker stock that was gripped in the chuck, can then best be turned on a mandrel of suitable size, to ensure concentricity of bore and exterior.

All work, such as pulleys, which are required to run true should, if possible, be turned on their own spindle. This method reduces possible inaccuracies in the mandrels, which may be quite considerable unless special hardened mandrels with lapped centres be employed. All centre recesses should be of the shape shown in Fig. 12 (*a*), *A* being the tailstock centre of the machine.

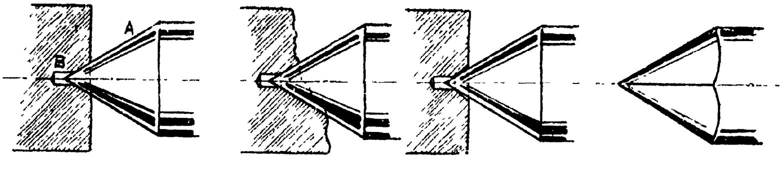
Mandrels

The mandrel provides an accurate method of locating and driving the work by holes or recesses and there are many types and variations in use.

A good standard mandrel is accurately centred, hardened, and finished by grinding, and has a slight taper of about 0·005 in.

To deal with a variety of washers, rings, collars, narrow bushings, and similar jobs, the stepped mandrel is an advantage.

Another form of mandrel which is particularly useful where considerable facing has to be performed is the grooved type. In this instance the mandrel is made with a series of shallow grooves along its length, and when the work has been forced suitably along it, the tool can travel past the edge of the bore into the relief space afforded by the groove.



(a) Correct centring.

(b) This causes uneven wear.

(c) Incorrect angle of centre.

(d) Square centre.

FIG. 12.—CORRECT AND INCORRECT CENTRING
Showing relation between lathe and countersunk angle.

Correct Shape of Centres

It should be borne in mind that during the period of the turning operation the centres are the bearings for the work, which in process of being machined undergoes very severe stresses. It is therefore important that the centre recesses in the job agree in angle with the machine centres, otherwise wear rapidly occurs while turning is in progress, and it becomes impossible for accurate work to be done. Fig. 12 (*c*) shows lathe and countersink angles which do not coincide, the bearing area being merely a narrow ring. Care should also be taken that the point of the centre is free, i.e. that recess *B*, Fig. 12 (*a*), is provided and is amply deep.

Lubricating Centres

Oil is used as a lubricant, and can be mixed with white-lead if turning is very heavy, the recess *B* acting as reservoir. As the work revolves and metal is being removed, heat is generated which increases the length of the piece, with consequent greater pressure on the centres; this would result in rapid wear and "galling up" of the centres, so that at intervals the back centre should be released, lubricant supplied, and the centre again run in, so that the job can be readily turned by hand without any shake.

Adjustment of the centre should be done only at the end of a cut, otherwise alteration of diameter is almost inevitable, so that before starting a finishing cut it is always prudent to see that the centre tension is correct and that it is adequately lubricated.

CENTRING

As lathe centres are now standardised at an angle of 60°, the requirements of correct centring are met by the use of a combined drill and countersink, usually known as a "centre drill." This may be used in a drilling machine.

Reasonable flatness and squareness of the ends should be secured by grinding or filing, as the piece will run badly between centres owing to uneven bearing area in the recesses as shown in Fig. 12 (*b*) should this not be attended to.

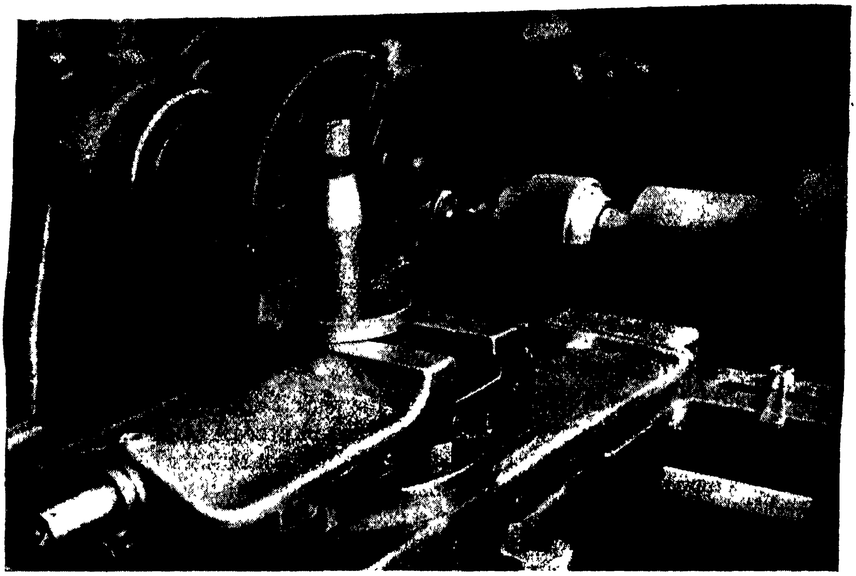


FIG. 13.—CENTRING IN LATHE

Showing centre-drill, held in drill chuck in tailstock, being fed up to work set in three-jaw concentric chuck. The materials in the toolpost serve as a reference for true running.

The position to drill can be found with tolerable accuracy by the use of scribing callipers, making four arcs, and using a centre punch to mark the centre.

Centring in the Lathe

A possibly simpler way and one which allows of really accurate centring is the one shown in Fig. 12, showing a bar set in a three-jaw concentric chuck, the centre drill being fed up by the drill chuck in the tailstock. The piece of material in the toolpost is for forcing over the bar should it be slightly bent; it also serves as a reference for true running, being fed to within $\frac{1}{32}$ in. and the constancy of gap noted while revolving the work. It is important that no outside restraint such as forcing bars be applied to the work whilst centring is in progress, or a broken centre drill will result.

The Square Centre and How to Use it

It is sometimes necessary to run truly between centres a piece whose original centre holes have been knocked up or otherwise damaged by careless handling. The correct procedure is to use a square centre as shown in Fig. 12 (*d*), and force the work on to it while revolving and keeping tension on the tailstock handwheel.

A square centre consists of a standard 60° centre with four flats ground on it, care being taken that the centre angle remains unaltered at the junction of

the flats. This procedure should be adopted until the piece runs true to the eye or a piece of chalk. Further truing necessitates some form of indicator.

A Precaution

When centre turning of any kind is in progress, the handwheel on the tailstock screw should have its handle placed on the back so that should the tailstock clamp come, or be left, undone, the tendency is for the centre to advance, thus avoiding all risk of the job flying out.

Avoiding Tool Chatter

Chatter is usually due to a badly ground tool or loose running on the centres, but when due to springiness of the work, it can only be cured by taking small cuts and keeping the cutting area small and the tool sharp. A piece of rubber, cotton waste, or leather placed between the driving pin and the tail of the carrier also helps matters.

SCREW-CUTTING

The principle of screw-cutting in a lathe is basically one of copying. The lead or guide screw is the master, and the threads on the job, either between centres or in the chuck, are merely a copy on a larger or smaller scale as desired.

The important part of a screw thread is its pitch, i.e. the distance from the top of one thread to the top of the next, measured in either inches or millimetres, and this, as before indicated, is governed by the lead screw, the diameter being dependent only on the position of the screwing tool, which is, of course, under the operator's control as in plain turning. It is not to be taken from the above that a lead screw is only capable of cutting threads of one pitch, for the gearing between the lathe spindle and the lead screw can be varied by means of the change wheels, thus enabling one lead screw to cut innumerable pitches, only dependent on the wheels available.

Change Wheels

These wheels are in sets supplied with the lathe, and are all interchangeable on the studs and spindles on the end train. A set usually consists of wheels, the number of teeth in which starts at 15, rises in 5s to 100, from 100 to 150 in 10s, together with one of 127 or 63 teeth for metric pitches, and one duplicate of one of the other (usually 40) for cutting the same pitch as the lead screw. (Note that 127 mm. = 5 in.)

The working out of the wheels required is quite simple, and although tables (Tables II and III) are given, a knowledge of the method employed is likely to be useful.

TABLE II.—CHANGE WHEELS FOR SCREW-CUTTING (METRIC PITCHES), GIVING SINGLE AND COMPOUND GEARING

Pitch in mm. to be cut	Guide Screw, ¼-in. Pitch				Pitch in mm. to be cut	Guide Screw, ½-in. Pitch			
	Single Gear		Double Gear			Single Gear		Double Gear	
	Driver	Driven	Driver	Driven		Driver	Driven	Driver	Driven
0·75	15	127	40 30	80 127	0·75	--	—	20 30	80 127
1·00	20	127	40 40	80 127	1·00	—	—	20 40	80 127
1·25	25	127	40 50	80 127	1·25	—	--	20 50	80 127
1·50	30	127	40 60	80 127	1·50	15	127	20 60	80 127
1·75	35	127	40 70	80 127	1·75	—	—	20 70	80 127
2·00	40	127	40 80	80 127	2·00	20	127	20 80	80 127

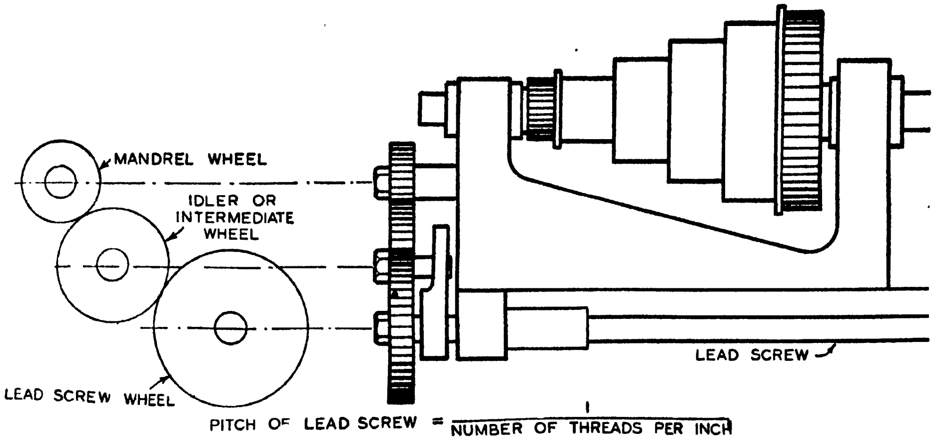
TABLE III.—CHANGE WHEELS FOR SCREW-CUTTING GIVING TWO SETS OF WHEELS TO EACH THREAD

Threads per in. to be cut	Guide Screw, ¼-in. Pitch		Guide Screw, ½-in. Pitch		Threads per in. to be cut	Guide Screw, ¼-in. Pitch		Guide Screw, ½-in. Pitch	
	Drivers	Driven	Drivers	Driven		Drivers	Driven	Drivers	Driven
	20 25	50 80	20 25	80 100		20	80	25 30	50 120
32	25 45	90 100	25 30	100 120	16	35 40	70 80	30 45	90 120
	20 30	40 105	20 25	70 100		20	70	20 75	100 105
28	20 30	60 70	20 45	105 120	14	30 40	60 70	20 50	70 100
	20 30	60 65	20 25	65 100		20	60	20	120
26	25 40	65 100	20 30	65 120	12	30 50	60 75	25 60	90 100
	20	120	25 30	75 120		40	110	20	110
24	20 40	60 80	20 25	60 100	11	30 40	55 60	30 60	90 110
	20	110	20 30	60 110		40	100	20	100
22	30 50	75 110	20 40	80 110	10	30 40	50 60	35 60	100 105
	20	100	20 40	80 100		40	80	20	80
20	20 40	50 80	20 35	70 100	8	20 75	50 60	35 60	70 120
	20	95	25 40	95 100		30	45	30	90
19	30 40	60 95	20 60	95 120	6	20 60	40 45	35 80	70 120
	20	90	25 40	75 120		40	40	30	60
18	30 40	60 90	35 40	105 120	4	30 105	90 35	40	80

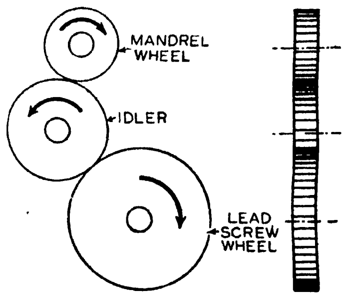
To find what Wheels are Required for Screw-cutting—Simple Train

The simplest case is one in which a simple train consists of one gear on the lathe spindle (mandrel wheel), one on the screw, and an odd wheel to gear up. The rule is:

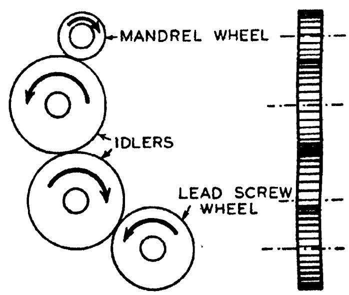
$$\frac{\text{Number of threads per inch on lead screw}}{\text{Number of threads to be cut per inch}} = \frac{\text{Number of teeth in mandrel wheel}}{\text{Number of teeth in lead screw wheel}}$$



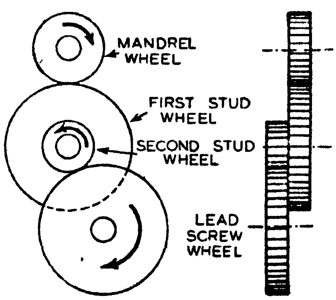
Arrangement of simple change gears on lathe.



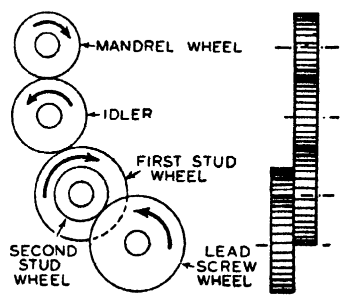
Simple train for cutting right-hand thread.



Simple train for cutting left-hand thread.



Compound train for cutting right-hand thread.



Compound train for cutting left-hand thread.

FIG. 14.—CHANGE-GEAR ARRANGEMENTS

Mandrel wheel = driver. First stud wheel = driven. Second stud wheel = driver. Lead screw = driven.

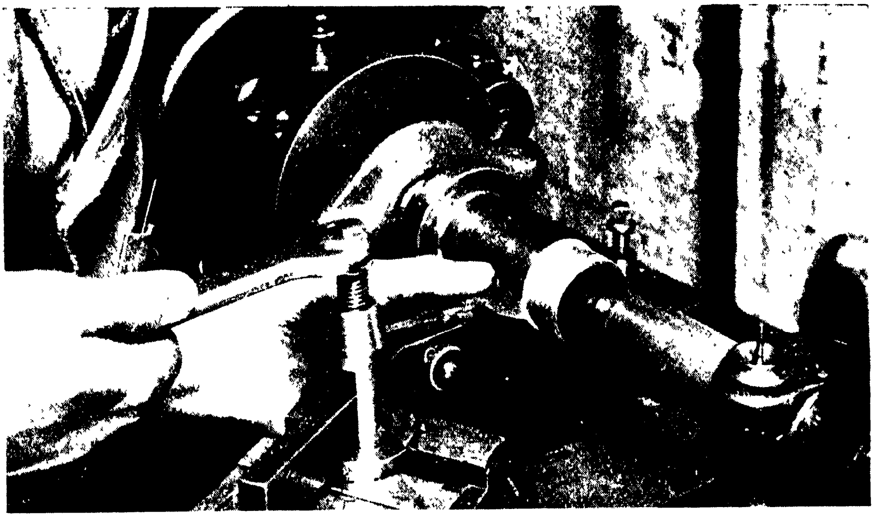


FIG. 15.—SETTING SCREW-CUTTING TOOL WITH A GAUGE

Set the screw-cutting tool to centre height and bring the flanks of the tool square with the work by means of a gauge as shown.

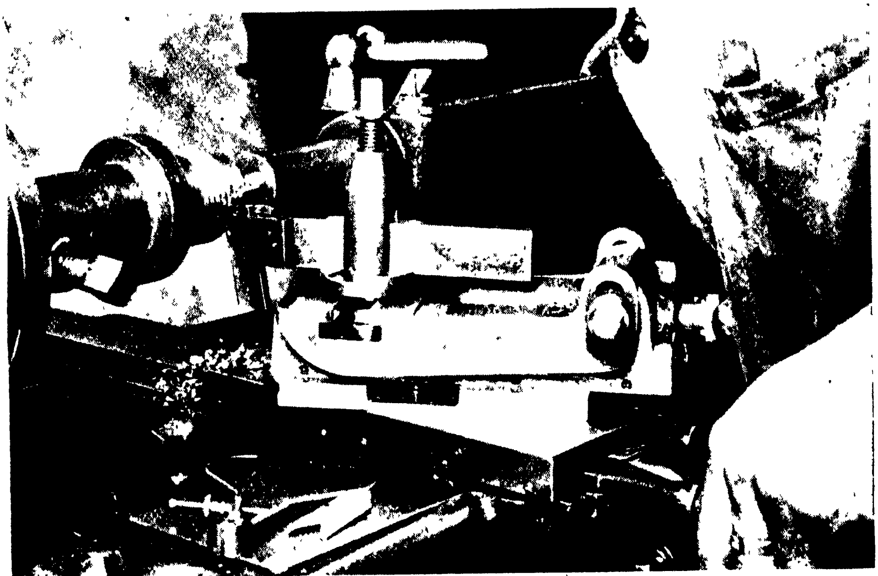


FIG. 16.—CUTTING A THREAD

When the tool has travelled the required length of thread, disengage the nut and at the same time withdraw the tool.

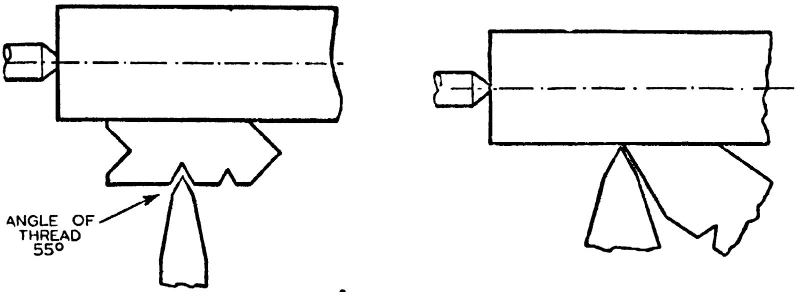


FIG. 17.—METHODS OF SETTING SCREW-CUTTING TOOL WITH CENTRE GAUGE

Taking the lead screw as having 4 threads per inch, and the pitch required to be cut to be 18 threads per inch, clearly the lead screw must run at $\frac{4}{18}$ of the speed of the work. Therefore multiply each of the figures by either 5 or 10 as most convenient, in this case 5. Thus:

$$4 \times 5 = 20$$
$$18 \times 5 = 90.$$

Therefore 20 and 90 are the required wheels, and as the screw must run slower than the work, the small wheel is the driver and goes on the spindle. A wheel of any convenient size is used to gear the two together; being both driver and driven, it exercises no influence as regards the speed ratio.

For fine threads and very often for odd pitches the simple train is unsatisfactory, resulting as it does in impossibly large gears; in this case the compound train is used.

Using Compound End Train

A compound train of gears is secured by first obtaining the ratio as above and then finding factors which can be multiplied by any suitable number to obtain the required train.

Taking an odd pitch, say $8\frac{1}{4}$ threads per inch with a lead screw of $\frac{1}{2}$-in. pitch, clearly the gearing here should be 8 to 33, or the screw should run at $\frac{8}{33}$ of the work speed. If these are multiplied as before, we get:

$$8 \times 5 = 40$$
$$33 \times 5 = 165.$$

This gearing is impossible with the wheels available, so that factorising must be resorted to, thus:

$$40 = 5 \times 8$$
$$165 = 11 \times 15.$$

Again multiplying by 5 we have:

$$25 \times 40$$
$$55 \times 75$$

for drivers and driven respectively.

To prove wheels, all that is necessary is to multiply all driven wheels together and multiply the product by the threads per inch of the lead screw. Division by the product of the drivers results in the number of threads to be cut.

Thus:

$$55 \times 75 = 4{,}125 \times 2 = 8{,}250;$$
$$25 \times 40 = 1{,}000$$
$$\frac{8250}{1000} = 8\tfrac{1}{4} \text{ threads per in.,}$$

therefore the train of gears is correct.

Rules for Cutting Multiple Threads

The width and depth of a square thread is half the pitch, the pitch being the distance from the centre of one thread to the centre of the adjacent thread.

Lead is the pitch multiplied by the numbers of starts or separate threads. Thus, if the pitch is $\frac{1}{4}$ in. with four starts, the lead will be $\frac{1}{4} \times 4 = 1$ in.

In cutting multiple threads, the change wheels to be used will have the same ratio as the pitch of the lead screw is to the lead of the thread to be cut. The mandrel wheel or first driver must have a number of teeth that is equally divisible by the number of starts or separate threads.

Having obtained a suitable set of change gears, the lathe is brought into position so that the lead-screw nut will engage with the lead screw, and the relative position of the lead screw, saddle, and job is marked in any convenient position. When this has been done, the mandrel wheel is divided and marked by the number of starts. Two teeth on the idler or the stud wheel are then marked, as shown in the diagram (Fig. 18).

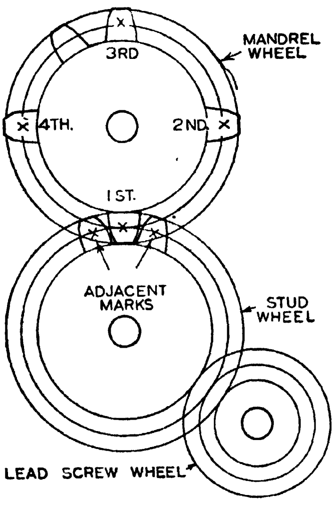


FIG. 18.—MARKING GEARWHEELS FOR CUTTING MULTIPLE THREADS

When one thread has been cut, the tumbler gear is lowered and the lathe pulled round by hand until the second marked tooth is engaged with the marked teeth on the idler or first stud wheel.

The cutting of square threads is dealt with in detail on page 269.

It should be noticed that the gears as set out revolve the lead screw in the same direction as the work, the slide rest travels in the direction of the headstock, and the resulting thread is right-handed. Should a left-hand thread be required, all that is necessary is to reverse the lead screw's rotation by inserting another wheel in the train, which has the desired effect. For the purpose of calculation, the reversing gear is both a driver and a driven, so that the number of teeth which it possesses is unimportant.

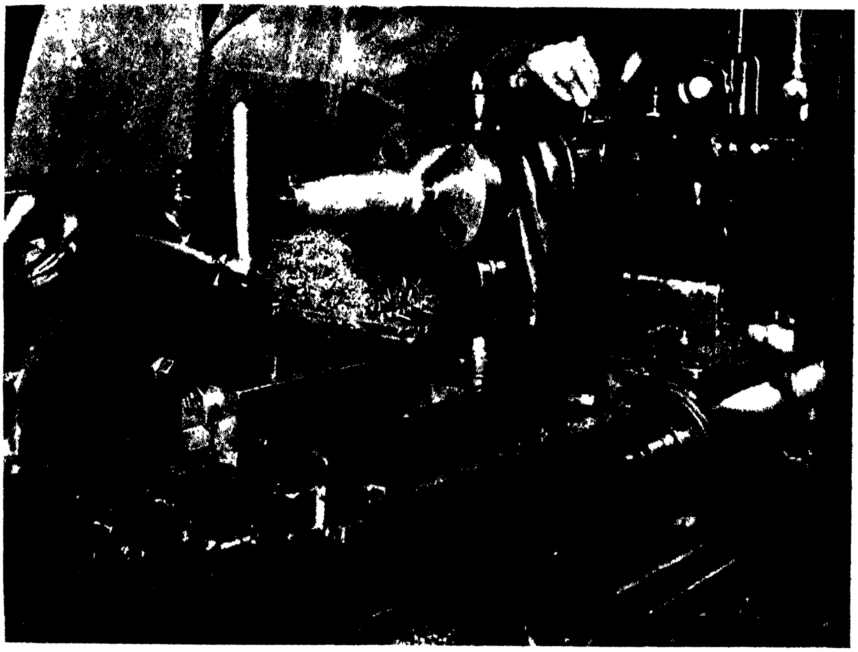


FIG. 19.—TAPER TURNING, USING SPECIAL TAPER-TURNING ATTACHMENT

The taper-turning attachment is shown in the foreground, the amount of taper being set by turning the hand knob on the left. Note that the cross slide is clamped to the taper guide block. (*Buck & Hickman, Ltd.*)

British and Metric Threads Compared

The ratio of metric to English pitches is as $\frac{63}{800}$ for $\frac{1}{2}$-in. pitch, and $\frac{63}{400}$ for $\frac{1}{4}$-in. pitch lead screw. The wheels may be calculated as follows: say, for example, that a screw of 5-mm. pitch is required to be cut on an English lathe with a lead screw of 4 threads per inch. The procedure to determine the wheels is to multiply the metric pitch by 63 and divide by 400 or 800, in accordance with the lead-screw pitch—in this case 400.

The lathes shown in Figs. 1 and 3 are both adapted to screw-cutting, and with suitable setting up can cut English or metric threads at will.

HOW TO TURN TAPERS

Unless the lathe is fitted with a taper-turning attachment (see Fig. 19), the methods of turning tapers depend on the taper required, both with regard to size, angle, and class of fit.

Short tapers, such as chamfers on collars or bolt heads, can be readily produced by inclining a side tool at the required angle and manipulating the slide-rest handles to suit.

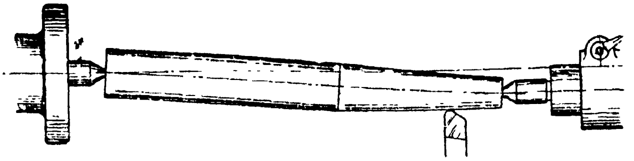


FIG. 20.—TAPER TURNING BY OFF-SETTING TAILSTOCK
Note how lathe centres are displaced; the tool travels parallel to the bed of the lathe.

Longer tapers may be turned by setting over the tailstock to half the actual taper required in the full length of the job. This method is illustrated in Fig. 20. Although, as clearly shown, this method results in misalignment of the centres, it is tolerated because the tool may be traversed by power, and if necessary screw threads may be cut.

Swivelling the Top Slide

More acute tapers can only be dealt with by means of swivelling the top slide to one-half of the included angle of the taper. The traverse in this case is necessarily by hand, so that care must be exercised if a good finish is desired. It is convenient to arrange matters so that two pieces which have to be tapered to match (say a hub and a shaft) can be turned one after the other to avoid resetting the slide. This often necessitates running the lathe backwards and placing the tool behind the job when turning the male part, but if the driving plate can be screwed on securely enough not to unscrew, it is an expedient well worth a trial.

Otherwise it becomes necessary to swing the top slide an equal number of degrees the other side of zero, which not only doubles any indexing error, but introduces further risk of inaccuracy should the pivot pin be the least bit easy. Top slide taper turning is equally applicable to objects driven between centres or held in the chuck, while the set-over tailstock method is only useful in the former case. For all taper turning it is essential that the tool height and the work-centre height coincide exactly, for should this not be the case, the taper will not be in accordance with the graduations of the index.

CHUCKS AND THEIR USES

The Chuck Equipment

Chucks of various types are among the most essential and useful equipment of the lathe. With a four-jaw independent chuck almost any shape may be held in such a manner that the necessary portions are presented to the tool. It is far simpler to set up a job dead true in a four-jaw independent than in any concentric chuck, for as the latter wear they commence to run untrue, and the only way to set the job true is to pack out the jaws to exactly the right amount. This procedure is troublesome to perform and unsatisfactory in operation. A concentric chuck is, however, particularly useful for many operations, so

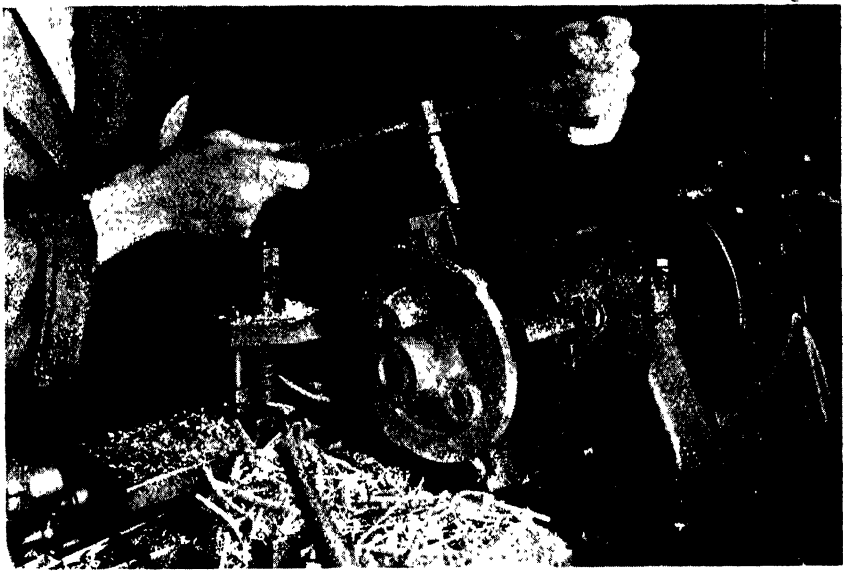


FIG. 21.—MACHINING OIL-FILTER COVER ON LATHE
Tightening up chuck jaws on work. Tool set up for facing the cover.

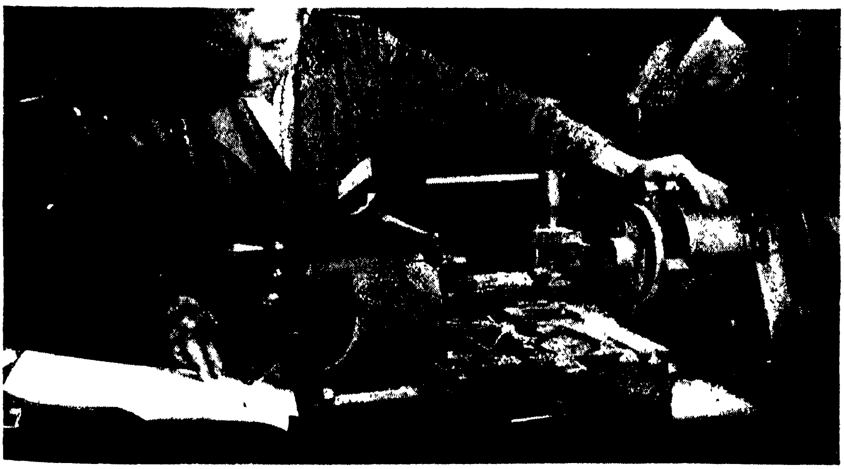


FIG. 22.—MACHINING OIL-FILTER COVER ON LATHE
Checking on drawing before commencement of job.

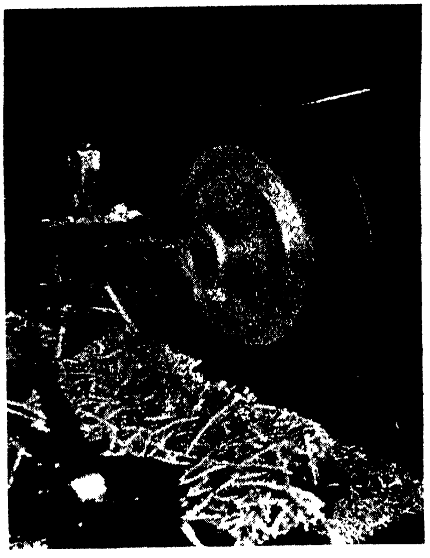


FIG. 23.—MACHINING OF OIL-FILTER COVER IN PROGRESS

FIG. 24.—MEASURING WIDTH OF GROOVE TURNED IN BOSS WITH CALLIPERS

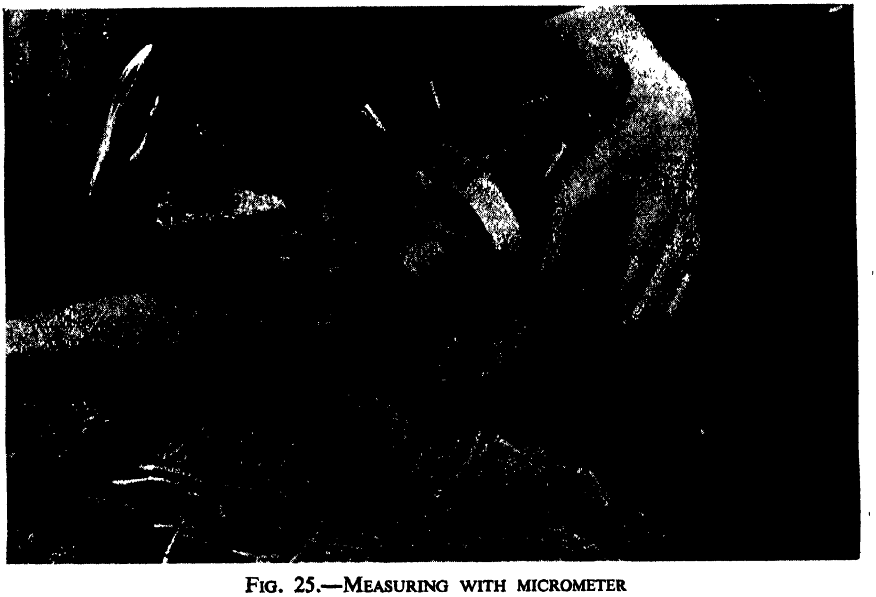


FIG. 25.—MEASURING WITH MICROMETER

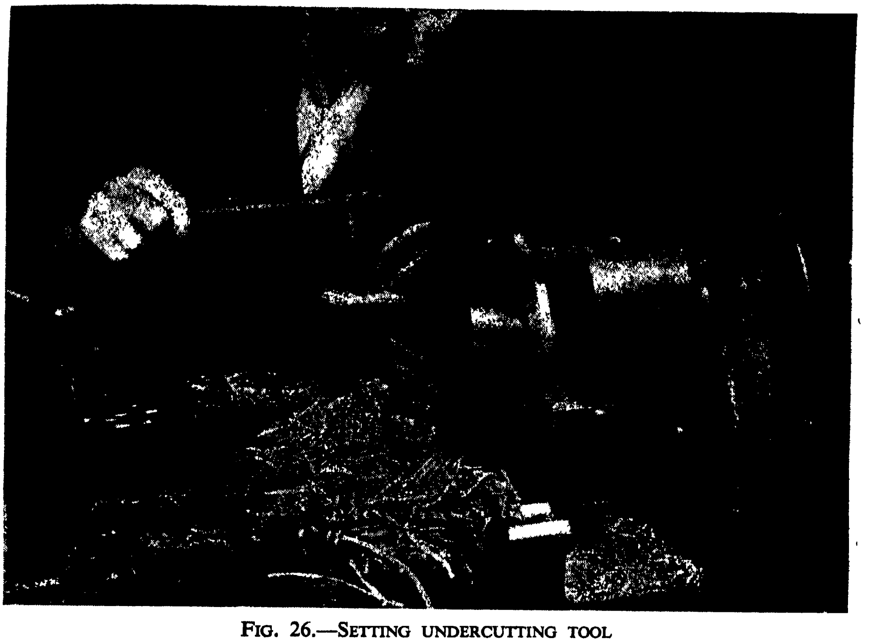


FIG. 26.—SETTING UNDERCUTTING TOOL

FIG. 27.—USING DEPTH MICROMETER

FIG. 28.—USING DEPTH RULE

that the inclusion of both types is advisable, together with the drill chuck and faceplate to complete the equipment.

A Typical Chuck Job

Fig. 29 shows a typical chuck job, the case in point being a fan-bracket casting in aluminium and requiring machining in two holes and four faces. A centre-punch mark was made in the centre of the large boss, and the casting set up in the chuck to this pop by means of tailstock centre. As the casting will require filing or polishing afterwards, the marks which the chuck jaws make are unimportant, but in general course all finished work should have brass or copper pads placed between the jaws and the job. Considerable power can be obtained by means of a chuck key, and, unless the above precaution is taken, ugly marks will be made in the job, visible evidence of careless work.

The drill is being fed up by the tailstock at the same time that the tool is completing the facing of the outside boss under power cross-traverse. Great care should be taken when holding thin tubes or similar work in a chuck, for, as remarked before, a powerful grip will result in a crushed or bruised job. All jobs requiring large quantities of stock to be removed should, if possible, be tackled by using the chuck. It has a powerful and rigid drive, and its flywheel effect allows the taking of large cuts.

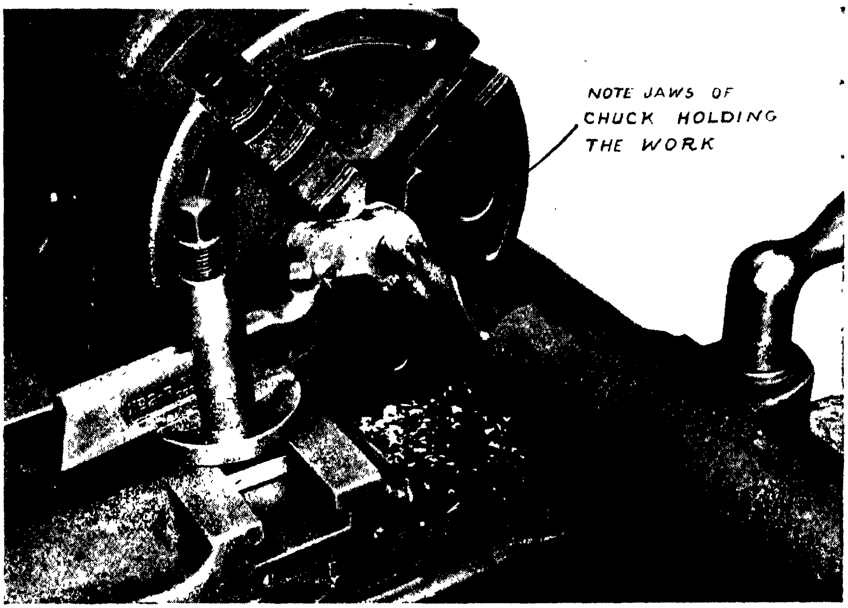


FIG. 29.—JOB IN FOUR-JAW INDEPENDENT CHUCK

An example of how a job of eccentric shape is held in a four-jaw independent chuck and how lathe may be used for drilling.

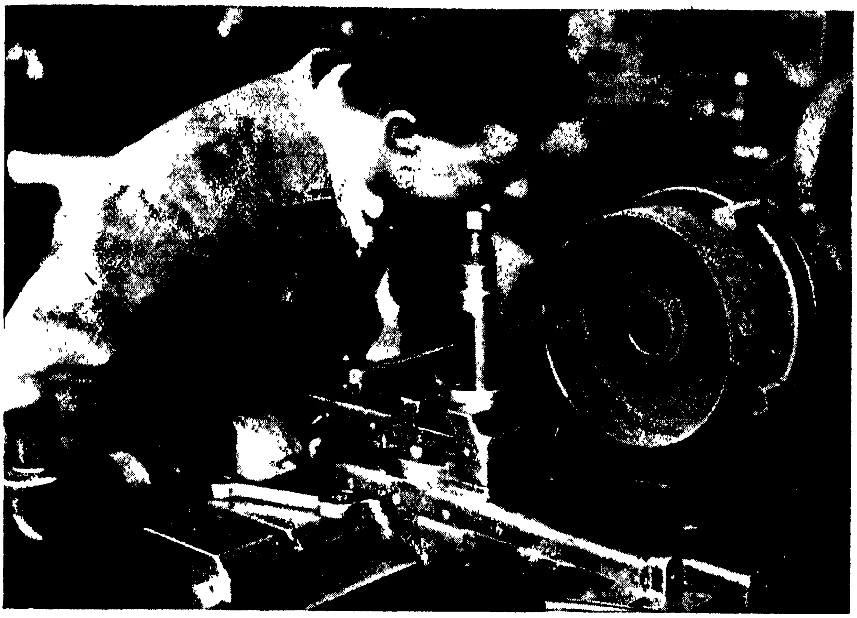


FIG. 30.—SKIMMING OUT SCORED BRAKE-DRUM

The tool used is the boring bar shown in Fig. 9 (*m*), with the bit set in the angular end to enable it to reach the bottom corner of the drum.

Large-diameter Work in Chuck

For large-diameter work the jaws are practically always reversible, so that really big jobs can be tackled, e.g. the case of a badly scored brake-drum, which is seen in Fig. 30 in process of being skimmed out. The tool used in this case is the boring-bar tool illustrated in Fig. 9 (*m*), with the bit set in the angular end to enable it to reach the bottom corner of the drum. For tooling out all but the smallest holes, the same bar should be used, one of its advantages being that it fits in the tool-post on a V-block, and need only be projected as far as is desired, thus obviating any unnecessary springiness.

To Set Up Job True in Chuck

In order to set up a job to run true in the chuck, a tentative setting of the jaws should be secured by means of the concentric lines marked on the chuck face. The work, tightened sufficiently for safety, is set revolving while a piece of chalk held in the hand is presented to it, this marking the high spot, which is set truer by adjusting the jaws concerned. Further accuracy is obtained by using a slide-rest indicator, either in the bore or on the exterior of the piece. In this way work may readily be set true to 0·001 in.

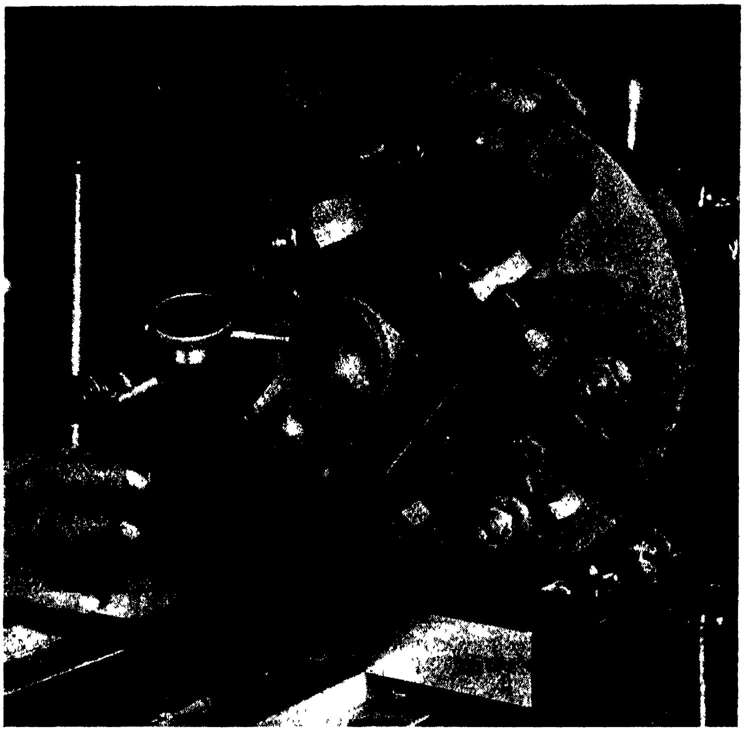


FIG. 31.—FACEPLATE WORK

Showing final check with dial gauge to see that work is true on faceplate. The scriber block is placed on a planer parallel, with the button of the gauge pressing against a machined part of the job, and the faceplate is revolved by hand. If the job is not true, the hand of the gauge will move backwards and forwards. Adjust the position of the job by tapping with mallet, until the dial hand remains steady during a whole revolution.

Faceplate Work

Faceplate is primarily for objects that could not be satisfactorily held in the chuck, and which, as a rule, do not need any heavy turning or boring operation. For example, with connecting rods it is extremely difficult to ensure that the hole be square with the longer axis of the rod if the job is tackled in the chuck, while if it is clamped on a faceplate the job is straightforward and the setting easy.

An example of the use of the faceplate is shown in Fig. 32 in boring the gudgeon-pin hole of a piston.

The angle plate ensures that the gudgeon-pin hole, in the piston concerned, is square with the piston body, and the clamping arrangements are quite simple.

It will be noticed that an inserted tool bar is again used in this case, owing to the length of the hole, while the piece of metal clamped to the top face of the plate is merely for the purpose of balancing roughly the off-set weight of the job, angle plate, and clamps. Were this not done, the bored hole would almost certainly not be round.

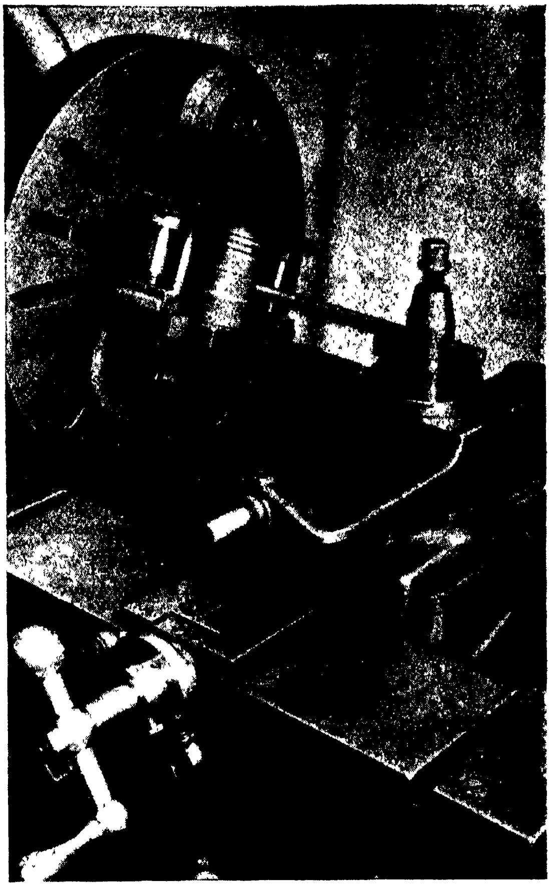


FIG. 32.—USE OF FACEPLATE IN BORING GUDGEON-PIN HOLE IN PISTON
Note angle plate and balance weight.

BORING

Boring in the lathe may be divided into two classes: cored holes and boring from solid or machined holes.

Drilling the Hole

For most work it is first necessary to make a hole of some sort, and this, of course, implies drilling. As large a drill as is practicable should be used, as tooling out a hole is very much slower than drilling, owing to the necessarily slender tools employed, so that as little as possible should be left in for the boring tool.

While it is quite possible to start a drill in the lathe without preliminary centring, it is preferable to put a starting hole in the work by means of a tool point or centre drill. Should the drill after starting show any tendency to run out of truth, it may be gently forced by a bar in the toolpost while being fed up by the tailstock, or may be withdrawn and the hole turned out true with a tool.

Dealing with Work which Cannot be Rotated

Jobs which by their size are incapable of being rotated may be machined by clamping them on to the lathe saddle and running the boring tool in the chuck.

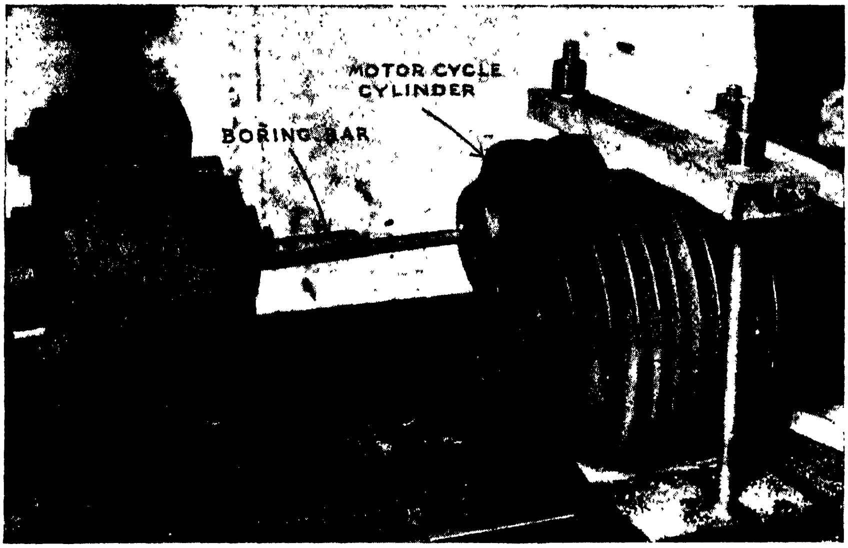


FIG. 33.—METHOD OF BORING WORK WHICH CANNOT BE ROTATED

The job is clamped to the lathe saddle, and the boring tool is run in a four-jaw chuck. The tool is thrown a shade more off centre after each traverse.

In this way boring, turning, and screw-cutting can be done, using power motions of the machine.

An Example

If possible a bar may be run between centres, carrying a projecting tool, but should the job in question be a cylinder or similar article with a closed end, a tool or a toolholder, preferably with a square shank, must be gripped in the four-jaw chuck and thrown a shade farther off-centre after each traverse. The illustration (Fig. 33) gives an idea of the method, although in this case the job is bolted direct to the saddle, thus losing all cross-motion. Valve-seat facing is in progress: note that the work requires accurate packing to the lathe centre heights.

No precise instructions can be given, as so much depends on the job and the type of lathe saddle; on some lathes it is almost impossible to fasten anything, while others are well provided with T-slots for bolts. Wood blocks cut to shape are about the best method of packing and securing work of this description, and if the machining is done with care, perfectly accurate work results, although the method is not particularly quick.

MEASURING TURNED AND BORED WORK

Outside Diameters

The accurate measuring of turned and bored work is of prime importance. For outside diameters, plain callipers can be used for roughing purposes to

FIG. 34.—TRUING GRINDING WHEEL BY USING PIECE OF BROKEN WHEEL

Move dresser from side to side across the face of the wheel. Remove only sufficient material to level up surface and expose a new cutting face.

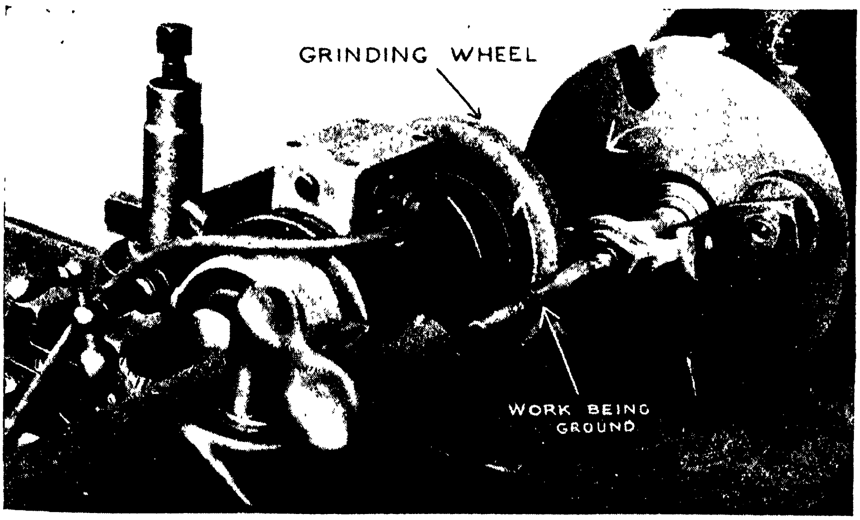


FIG. 35.—USING ATTACHMENT FOR PLAIN CYLINDRICAL GRINDING

The electrical grinding attachment is gripped in the tool-post by means of a shank attached to the body of the motor. Note that the carrier is held on both sides.

within 0·010 in., but for finishing a micrometer or vernier is almost essential. The measuring surfaces of both the foregoing should be wiped immediately prior to using, thus guarding against false measurements due to dirt.

Bores

For bores, a pair of inside callipers supplemented by an ordinary micrometer are satisfactory, solid plug gauges being used when standard holes are required. Really the job it is required to fit is the best gauge of all, as its use obviates the risk of mistaken measurements. Care must be taken, when taking calliper readings, particularly internal, that the callipers are held truly square, thus giving true diameters.

Vernier and Micrometer Callipers

Whereas the micrometer is usually made in sizes such as 0–1 in., 1–2 in., 2–3 in., etc., and for measuring outside diameters only, the range of the vernier for outside diameters is from 0 to 4 in., 6 in., 9 in., etc., according to the length of the rule, and for inside diameters they usually start at $\frac{1}{4}$ in., extending to the limit as for outside diameters. In the 4- and 6-in. verniers it is usually possible to measure bars up to 3 in. diameter anywhere along their length, but for sizes over this it will be found necessary to take the measurement across the end of the bar.

GRINDING ON THE LATHE

Grinding Machine and Lathe Compared

The important feature of a grinding machine is rigidity. Greater weight and more robust design are noticeable differences between a grinding machine and a lathe. Vibration must be eliminated as much as possible if a good finish is to be expected.

Therefore, when we fit a grinding spindle to the cross slide or top rest of a lathe, it would be unfair to expect the same finish resulting as we should get from a machine which was built solely for grinding; more so is this the case when external or face grinding is being done, for we are then using a much bigger wheel.

When to use Grinding Method

On a material which can be turned, i.e. a job that is not hardened, it is possible to get a much better finish by turning, followed by filing and emery cloth, in the lathe, than by the use of a grinding attachment.

This being so, it is obvious that this method of grinding is reserved for work that is too hard for the standard lathe tools.

Protection of Lathe against Grinding Dust

A further very important point to remember when using the lathe for grinding purposes is the damaging effect that the grinding dust has on

the sliding surfaces of the machine, and every precaution must be taken to cover and afterwards clean down any parts which this injurious dust is likely to harm.

The action of grinding and the nature and selection of the grinding wheels used are explained in the section on Toolroom Grinding, commencing on page 446 of this volume.

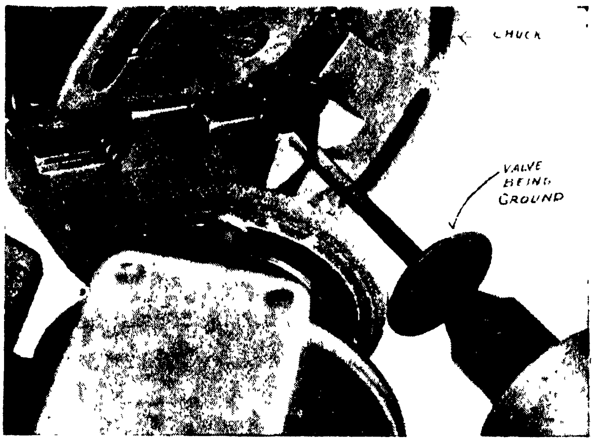


FIG. 36.—VALVE GRINDING ON LATHE
Using the same grinding attachment as is shown in Fig. 35

Wheel Truing

A piece of broken grinding wheel will be found suitable for truing the wheel, but it requires more skill in handling than the diamond tool which is used in large workshops. Fig. 34 will explain the method of holding the dresser to the wheel, it being moved from side to side across the face of the wheel, removing only sufficient material as is necessary to level up and expose a new cutting face.

Wheel Speeds

A good average wheel speed for *external* grinding varies between 5,000 and 6,000 ft. per minute, and for *internal* grinding 4,000 ft. per minute is considered satisfactory, but speeds as low as 1,000 ft. per minute have been used with success; the rigidity of the wheel spindle seems to be of more importance than the speed for internal grinding.

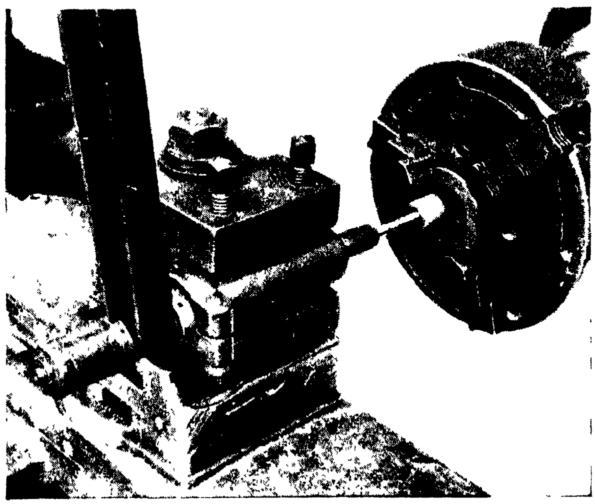


FIG. 37.—INTERNAL GRINDING USING ATTACHMENT BELT DRIVEN FROM COUNTERSHAFT

Work Speeds

	Surface feet per minute
External grinding	69
Internal grinding	120
Surface grinding	20–30

In traversing the wheel past the work, attention must be paid to the revolutions per minute of the work. A satisfactory traverse is two-thirds the width of the wheel per revolution; this ensures even wear of the wheel.

Grinding Attachments for Lathes

There are two types of grinding attachments for lathes—the electrical and the countershaft-driven.

Electrical Type

An electrical grinding attachment is shown in Fig. 35. It has a shank of the standard tool section attached to the body of the motor, the shank being gripped in the toolpost just in the same way as a turning tool.

When ordering a grinder of this type, consideration must be given to the direction of rotation of the spindle, which should be right-hand (clockwise) when facing the grinding-wheel end.

The spindle projects approximately 1 in., and must be threaded left-hand to suit the above condition; to it can be attached the wheel collet for external grinding.

The speed of the motor is constant, so that correct grinding speed is only obtained with certain diameters of wheels, which is a disadvantage, but these grinders are very handy, being self-contained, and can be used as portable grinders, or gripped in a vice and used as bench grinders.

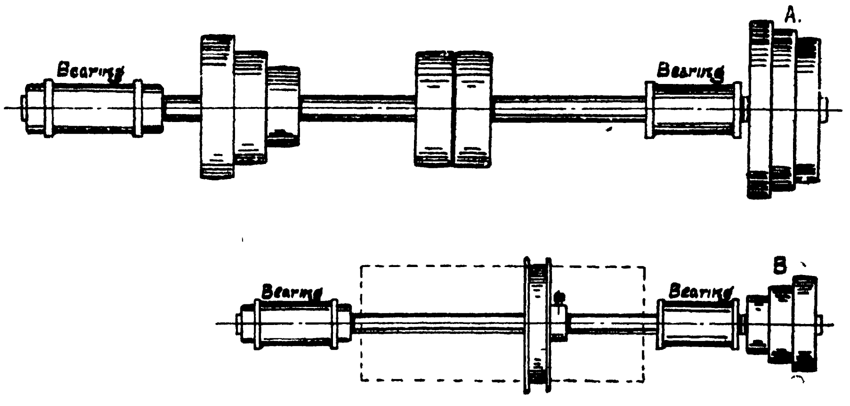


FIG. 38.—AUXILIARY COUNTERSHAFT FOR GRINDING ON THE LATHE

Position of drum is shown by dotted line. There is a choice of speeds to the wheel spindle with this attachment, obtainable from the cone pulleys *A* and *B*.

The Countershaft Type

There are several of this type, of which the "Drummond" attachment is an example.

That used in Fig. 37 may perhaps have greater appeal; it is a "tube"-type spindle from an old Churchill internal grinder.

The driving of the spindle is from an extra countershaft placed alongside, and driven by the existing shaft.

For the drive down to the spindle it is sufficient to have a large-diameter flange pulley on this secondary shaft, which can be adjusted along the length to a position approximately above the centre of the proposed travel of the grinding spindle, and as this travel is comparatively short, the flanges keep the belt on the pulley.

Alternatively, a large-diameter drum is required which obviates the trouble of adjustment, but which is a higher initial expense.

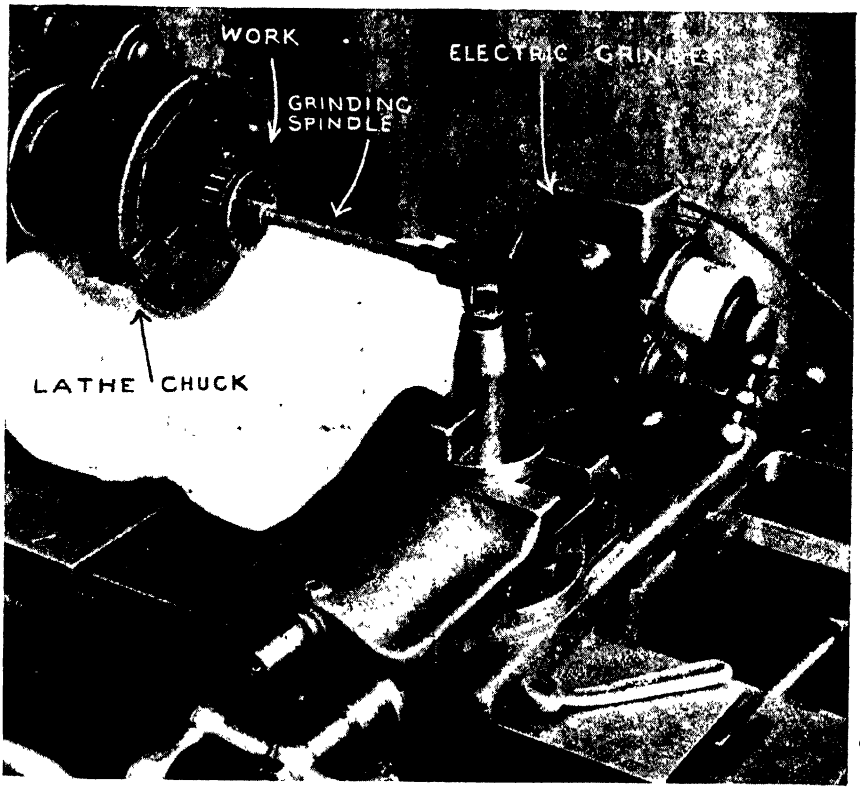


FIG. 39.—INTERNAL GRINDING ON THE LATHE, USING ELECTRICAL ATTACHMENT

This countershaft arrangement is shown in plan, Fig. 38, the dotted line showing the position of the drum.

The latter type of attachment has the advantage of having a choice of speeds to the wheel spindle, which is obtained from the cone pulleys *A* and *B*, Fig. 38.

Examples of Grinding Jobs

The general principles of turning hold good when we come to grinding, the wheel merely taking the place of the turning tool.

In most of the examples given, the work occupies the same relative position to the grinding wheel as it did to the turning tool, and the traverse of, and feed to, the wheel is effected by the same controls.

In grinding it is important that the direction of motions of the wheel and work must be opposite to one another where the grinding is taking place.

Plain Cylindrical Grinding

Plain cylindrical grinding using the electrical grinder is shown in Fig. 35, the direction of rotation being indicated by the arrows. A particular point to notice is that the carrier is held on either side, which is always necessary in grinding, otherwise an uneven finish will result; various means of doing this will suggest themselves.

In Fig. 36 we have the regrinding of a valve, the centre giving the necessary support, the compound tool rest providing the correct angle as in the turning of a cone.

Internal Grinding

An internal grinding operation is shown in Fig. 39, where the method of gripping the electric grinder is clearly shown. The wheel will have to make contact on the far side of the bore in the gear being ground, because of the direction of rotation of the motor.

Internal grinding is shown in Fig. 37, the job being a hardened-steel washer gripped in the three-jaw chuck, the old tube spindle being used; the method of gripping this spindle could be varied to suit the conditions and type of lathe in use.

Here the wheel is shown in contact on the near side (to the operator), which is the ideal way, as the operator has a better view of the grinding action, but one of the driving belts must be crossed, to provide the right direction of rotation.

Face-grinding operations can also be carried out, using a "cup" wheel.

Where any considerable amount of grinding has to be done, a special grinding machine or "grinder" should be installed. Details concerning the operation of such machines will be found in the section beginning on page 388.

The examples given above illustrate the versatility of the lathe, which can be adapted for many processes in addition to its normal application for the turning of metals.

II.—SOME EXAMPLES OF TURNING PRACTICE

In the following pages various jobs have been selected and the operations involved in carrying them out described step by step. The examples given are typical of the types of work which lathe operators have to do frequently. The first example is phosphor-bronze bushing.

MAKING PHOSPHOR-BRONZE BUSHING

Fig. 40 shows the phosphor-bronze casting from which the bush is to be made. Owing to there being insufficient material in the casting for chucking, the bush will have to be made in two operations.

First Operation

Locate in a four-jaw chuck as concentrically as possible, so that clean cuts can be taken on both the inside and outside of the casting.

The outside of the flange is faced and the flange is also finished to its correct outside diameter of 4½ in. One setting of the tool will complete this operation.

Boring the Bush

The bush is bored with a standard boring tool, set to not lower than the centre line, and not more than a fraction above. The bush is bored out to 0·002 in. oversize (2 + 0·002 in.).

Second Operation

Centres and driving plate replace the chuck. The partly finished bush is forced on to a hardened and ground mandrel. Only sufficient force is used to ensure that the bush does not slip under the pressure of the tool point.

Mandrel Lubrication

It is important that the centres of the mandrel are not scored by under-lubrication and consequent over-heating. Therefore a drip of medium engine oil and red-lead should be applied when the mandrel is placed between centres.

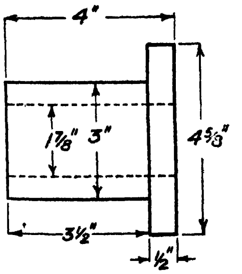


FIG. 40. — PHOSPHOR-BRONZE CASTING FROM WHICH BUSH IS TO BE MADE

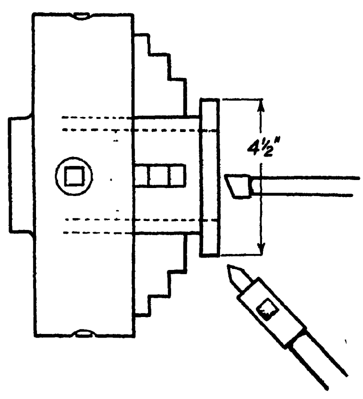


FIG. 41.—BUSH CASTING IN CHUCK FOR FACING FLANGE AND BORING

The bush is bored out to two-thousandths oversize to allow for closing in of bore when bush is pressed into place.

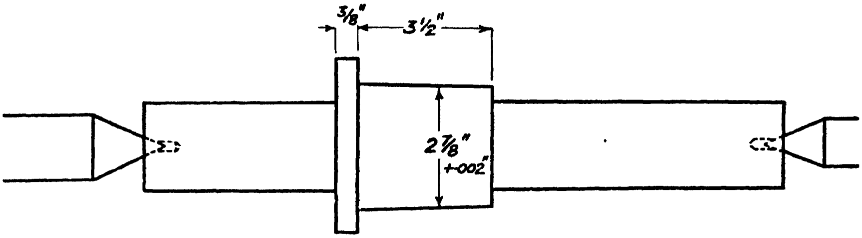


FIG. 42.—PHOSPHOR-BRONZE BUSH ON MANDREL FOR OUTSIDE MACHINING

Allowance for Mandrel Expansion

The tailstock screw should be readjusted just after starting the cut to see if it has expanded with the heat generated during cutting. The tailstock screw may have to be adjusted from time to time, and therefore should not be overlooked.

Preserving Concentricity

The outside of the flange, having been turned at the same setting as the inside of the bush, should now run true if the mandrel is true. Observe this before commencing operation.

Finishing the Outside

Rough and finish the outside with the same tool and same setting as when the flange was turned. The finished diameter of the main body will be 2⅞ + 0·002 in. This oversize is to allow for pressing into bush housing.

Reason for Over-size Bore

When the bush is pressed home the bore will close in and save the reamer considerable work. The 0·002 in. oversize to which the bore was turned represents a sheet of phosphor bronze 6¼ × 3½ × 0·002 in., which the reamer would otherwise have had to remove. The phosphor-bronze bush will cushion to a certain extent, but as the outside of the bush will be forced in to 2⅞ in., this will amount to metal equal to 9 × 3½ × 0·002 in., more than ample to counterbalance that taken from the bore.

Mandrel Taper

The taper of standard lathe mandrels is 0·006 in. to the foot. The job should be removed by placing on a swage block and the

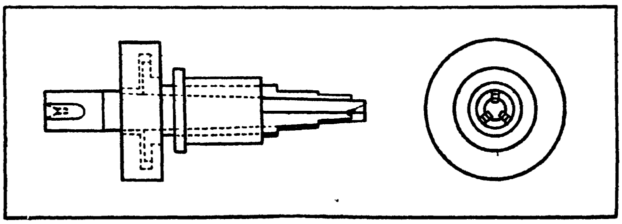
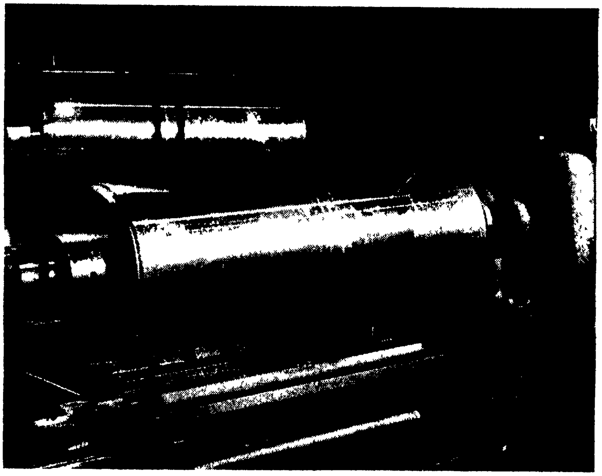


FIG. 43.—BUSH FITTED TO EXPANDING MANDREL FOR OUTSIDE MACHINING

FIG. 44.—METHOD OF TURNING THIN GUNMETAL STRIPS

A special conical driver, shown "ghosted," is employed, which has projecting inserts that bite into one end of the casting. (*Associated British Machine Tool Makers, Ltd.*)



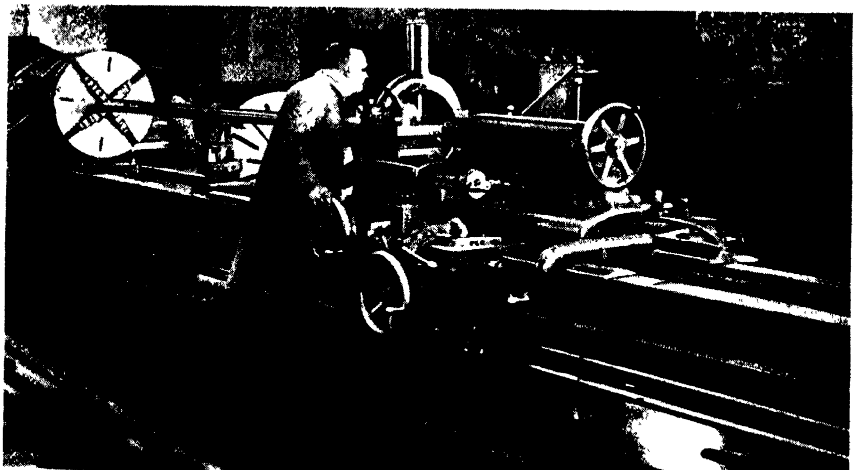


FIG. 45.—TURNING A HOLLOW STAINLESS-STEEL SHAFT, 2¾ IN. DIAMETER × 12 FT. 6 IN. LONG ON A LANG 36-IN. SWING SLIDING, SURFACING, AND SCREW-CUTTING LATHE WITH 18-FT. BED

The illustration shows the finish turning of a hollow stainless-steel shaft for a special-purpose machine. It is 12 ft. 6 in. long by 3¾ in. top diameter, with a wall thickness of only $\frac{5}{16}$ in. In addition to this, the shaft is tapered 0·020 in. in its length, the diameters at all points being held to tolerances of ± 0·002. In spite of the use of two steadies, seen mounted on the bedways, only very light cuts have to be taken to avoid flexing the shaft. The job is completed in about four days. (*Associated British Machine Tool Makers, Ltd.*)

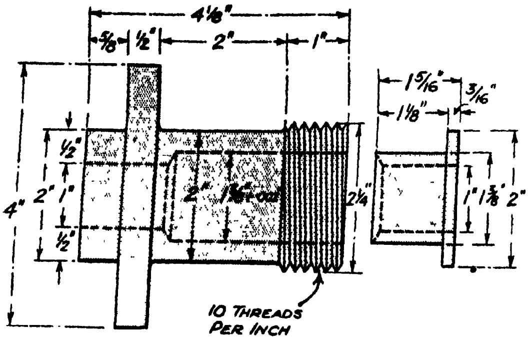


FIG. 46.—VALVE-ROD GLAND WITH PACKING COLLET

Showing the finished machined casting after the turning operations described in the text.

mandrel knocked out with a lead hammer. The centres are not damaged thereby.

Cutting Lubrication

When only one bush is being turned, the work can be turned dry; but with all high-speed work, either lard oil or cutting compound should be used. Keeping the mandrel cool is the chief object of the turner. Mandrels are expensive tools.

TURNING VALVE-ROD GLAND CASTING

It is proposed to describe the methods employed in turning a phosphor-bronze valve-rod gland casting. Fig. 47 shows the casting as delivered to the operator. The overall dimensions should be specially noted.

The casting can be turned dry. All operations are carried out in a self-centring chuck.

Placing in Chuck

Grip the job in the chuck as shown in Fig. 48. Place the part that eventually will be screwed well into the chuck, so that the strain on the jaws is immediately over the part gripped.

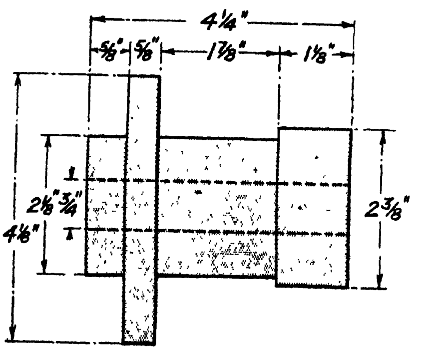


FIG. 47.—DIMENSIONS OF PHOSPHOR-BRONZE VALVE-ROD GLAND CASTING BEFORE MACHINING

Showing the casting as it is delivered to the operator.

The First Cut—Roughing Out

With a rough cutting-out tool, cut well under the skin of the casting so as to avoid cutting through sand.

Further Cuts

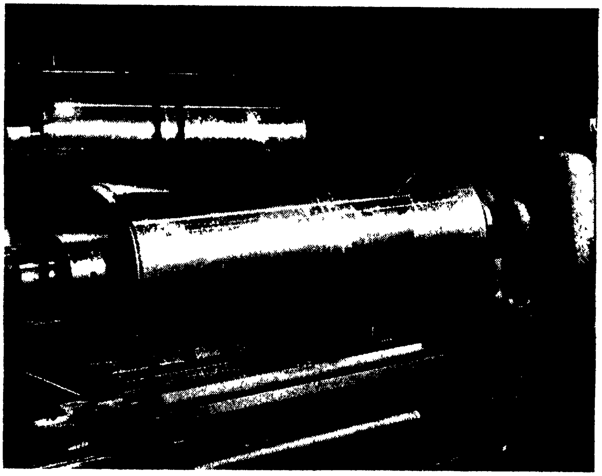
After roughing, further cuts should be taken until the flange is exactly 4 in. in diameter and the rebate 2 in. in diameter.

Finishing the Flange

Without moving the job, the other side of the flange can be roughed and finished to ½ in.

FIG. 44.—METHOD OF TURNING THIN GUNMETAL STRIPS

A special conical driver, shown "ghosted," is employed, which has projecting inserts that bite into one end of the casting. (*Associated British Machine Tool Makers, Ltd.*)



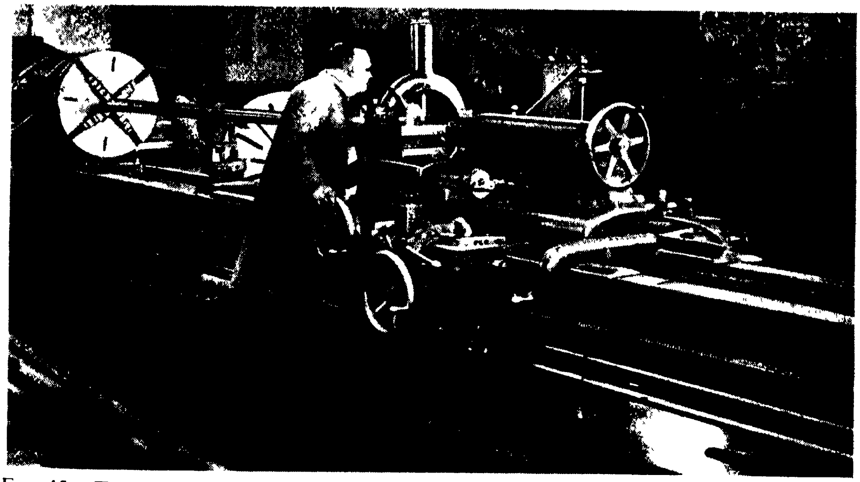


FIG. 45.—TURNING A HOLLOW STAINLESS-STEEL SHAFT, 2¾ IN. DIAMETER × 12 FT. 6 IN. LONG ON A LANG 36-IN. SWING SLIDING, SURFACING, AND SCREW-CUTTING LATHE WITH 18-FT. BED

The illustration shows the finish turning of a hollow stainless-steel shaft for a special-purpose machine. It is 12 ft. 6 in. long by 3¼ in. top diameter, with a wall thickness of only $\frac{5}{16}$ in. In addition to this, the shaft is tapered 0·020 in. in its length, the diameters at all points being held to tolerances of ± 0·002. In spite of the use of two steadies, seen mounted on the bedways, only very light cuts have to be taken to avoid flexing the shaft. The job is completed in about four days. (*Associated British Machine Tool Makers, Ltd.*)

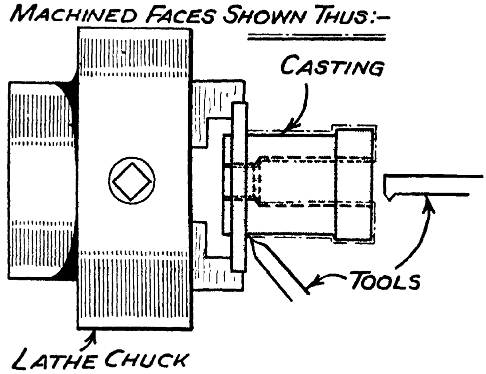


FIG. 49.—JOB IN CHUCK FOR FINISHING

Boring and machining the casting. The hole is enlarged to 0·002 in. oversize to take collet easily. The portion for screwing is turned to 0·001 in. undersize.

If the lathe has a ¼-in. pitch lead screw, the wheels to use will be 20 on the spindle and 50 on the lead screw; if ½-in. pitch lead screws, 20 and 100.

As most small lathes have ¼-in. pitch lead screws, it will be necessary to mark chuck and lead screw to ensure that the tool strikes the same place every time the "nut" is engaged. This is carried out by tightening down the tailstock so that the saddle is brought back to the same spot every time. When the lines on chuck and lead screw coincide, the nut is engaged, and only then.

How to cut the Thread

As the thread groove is deepened, it is as well to rub chalk on the surface. The next time the tool traverses the job, chalk will only be left on the uncut portion of the thread. When only a thin chalked line of thread is showing, the hand rest can be substituted for the tool.

Rounding Thread with Hand Chaser

Run the hand chaser of 10 pitch along the thread in order to produce the rounded top which is the characteristic of all Whitworth threads.

With American 60° threads the chaser is not necessary, as the thread is flat, top and bottom.

Use the nut as a gauge to locate final depth of thread.

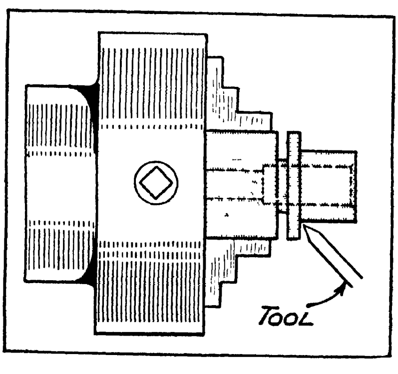


FIG. 50.—A COLLET IS MADE FROM STOCK CASTING AND PARTED OFF WHEN FINISHED

This shows job just before the final and parting cut separating it from the main casting has been taken.

Turning the Collet

The collet is an easy matter. It is made from a short length of 2⅛ × ¾-in. cored phosphor bronze. Hold a length of the metal in the chuck with not more than 1⅝ in. projecting and rough out to a little over the finished sizes given. Then bore out to 1 in., as has been done to the gland. Turn the outside to the finished size and face off end to 45°.

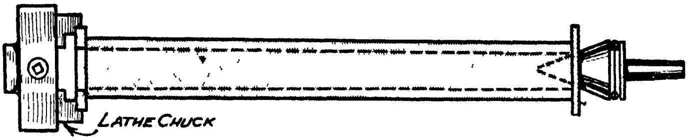


FIG. 51.—FITTING LONG-FLANGED PIPE IN LATHE
One flange is fixed in self-centring chuck and the other end in a running centre.

Part off the nearly finished job to allow for cleaning up the $2 \times \frac{3}{16}$-in. flanged top. When cut off, replace in chuck and face off. Dead concentricity does not matter, as hole and body have already been finished to size.

Fig. 50 shows job just before the final and parting cut separating it from the main casting has been taken.

TURNING FACES OF LONG FLANGED PIPE

It is very often necessary to face up the flanges in pipe work. Two typical jobs are described here—turning the faces of long flanged pipe and of a 90° pipe bend.

Using a Running Centre

Fix one flange in the self-centring chuck and centre the other end on a running centre, an enlarged view of which is shown in Fig. 52.

The centre runs on a spindle and the thrust is taken by a ball-thrust race.

Fitting Pipe in Lathe

Owing to length and weight of the pipe, wood blocks should be placed on the lathe bed to support the pipe whilst it is being chucked and centred. The height of the blocks should be just under the height of the work when centred. Open out the jaws of the chuck and slide the pipe between the open jaws. Bring up the tailstock and running centre, which will slightly take the weight of the pipe at the tailstock end. Tighten the chuck jaws securely and readjust the tailstock screw.

Turning the Face of the Flanges

The knife tool shown in Fig. 53 is used for facing. Light cuts only must be taken, as the point of the tool is very slender and any heat generated is not readily radiated away. It will be impossible to turn the face right to the inner edge, as the centre will be damaged by so doing; therefore remove the last $\frac{1}{32}$ in. by chisel or file.

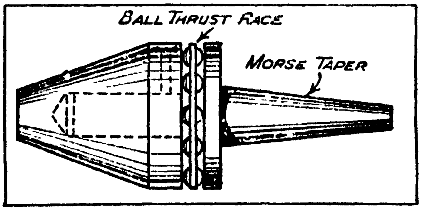


FIG. 52.—A RUNNING CENTRE
Used for centring long-flanged pipe in lathe, as shown in Fig. 51.

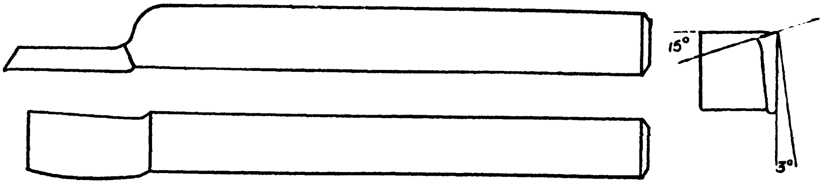


FIG. 53.—CAST-STEEL TOOL FOR TURNING FACES OF LONG-FLANGED PIPE
Tool tempered to medium straw colour.

Cutting Lubricants to Employ

Cast iron and brass pipes are cut dry, copper and steel with oil or soapy water, aluminium with a mixture of paraffin and commercial turpentine.

TURNING FACES OF 90° PIPE BEND

Setting up on Angle Plate

Lightly attach angle plate to faceplate and bolt down to it the 90° pipe bend. Lay a long straightedge along the face of the bend, and only finally tighten down when the straightedge is parallel to the faceplate. The distances *A* and *B* in Fig. 54 should be equal.

Setting Angle Plate on Faceplate

The angle plate should be placed so that the centre line of the lathe coincides with the centre line of the pipe hole. With the aid of a chalk stick held lightly in the fingers, the hole in the flange can be used to centre the job. When the chalk touches all round the hole equally it is central.

Balancing the Work when Turning

As the weight of the angle plate is on one side of the faceplate, it will be necessary to counterbalance it, as shown in Fig. 55. The balance may be a special weight or a series of change wheels fastened to the plate with a long bolt.

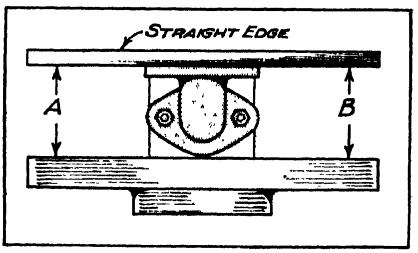


FIG. 54.—SETTING UP PIPE BEND ON ANGLE PLATE

Tooling the Flanges

Heavy cuts cannot be taken owing to the shape of the work and the method of fastening down. Cutting from outside to inside the tool will only touch the job twice in a revolution, therefore a heavy cut would be too much of a jar to the work. It is as well to advance the tool slowly and turn the work by

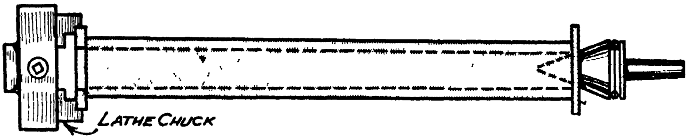


FIG. 51.—FITTING LONG-FLANGED PIPE IN LATHE
One flange is fixed in self-centring chuck and the other end in a running centre.

Part off the nearly finished job to allow for cleaning up the 2 × $\frac{3}{16}$-in. flanged top. When cut off, replace in chuck and face off. Dead concentricity does not matter, as hole and body have already been finished to size.

Fig. 50 shows job just before the final and parting cut separating it from the main casting has been taken.

TURNING FACES OF LONG FLANGED PIPE

It is very often necessary to face up the flanges in pipe work. Two typical jobs are described here—turning the faces of long flanged pipe and of a 90° pipe bend.

Using a Running Centre

Fix one flange in the self-centring chuck and centre the other end on a running centre, an enlarged view of which is shown in Fig. 52.

The centre runs on a spindle and the thrust is taken by a ball-thrust race.

Fitting Pipe in Lathe

Owing to length and weight of the pipe, wood blocks should be placed on the lathe bed to support the pipe whilst it is being chucked and centred. The height of the blocks should be just under the height of the work when centred. Open out the jaws of the chuck and slide the pipe between the open jaws. Bring up the tailstock and running centre, which will slightly take the weight of the pipe at the tailstock end. Tighten the chuck jaws securely and readjust the tailstock screw.

Turning the Face of the Flanges

The knife tool shown in Fig. 53 is used for facing. Light cuts only must be taken, as the point of the tool is very slender and any heat generated is not readily radiated away. It will be impossible to turn the face right to the inner edge, as the centre will be damaged by so doing; therefore remove the last $\frac{1}{32}$ in. by chisel or file.

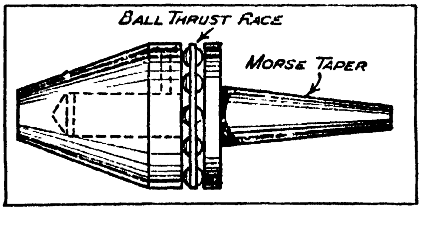


FIG. 52.—A RUNNING CENTRE
Used for centring long-flanged pipe in lathe, as shown in Fig. 51.

the work. The wheels used will have an equal number of teeth, both on the spindle and lead screw.

Grinding Tool to Correct Angle

The tool actually moves $\frac{1}{2}$ in. along the shaft while the circumference ($2 \times 3{\cdot}1416$ in.) is passing before its cutting face. There are two angles concerned in grinding the tool for cutting square threads—the angle of the leading side and that of the following side of the tool. The operator may arrive at the angles required for any particular square thread either graphically or by trigonometrical formula; both these methods are illustrated in Fig. 57.

Allowance for Tool Clearance

Fig. 57 also gives an enlarged tool-section view of the tool when actually cutting the thread. It will be seen that a clearance is allowed on each side of the tool, the amount of which is based on the material being machined. It is wise to allow $1\frac{1}{2}°$ under any circumstance. It is most important that the cutting edge of the tool measures exactly 0·250 in. when the anvils of the micrometer calliper are *horizontal* and not following the clearances.

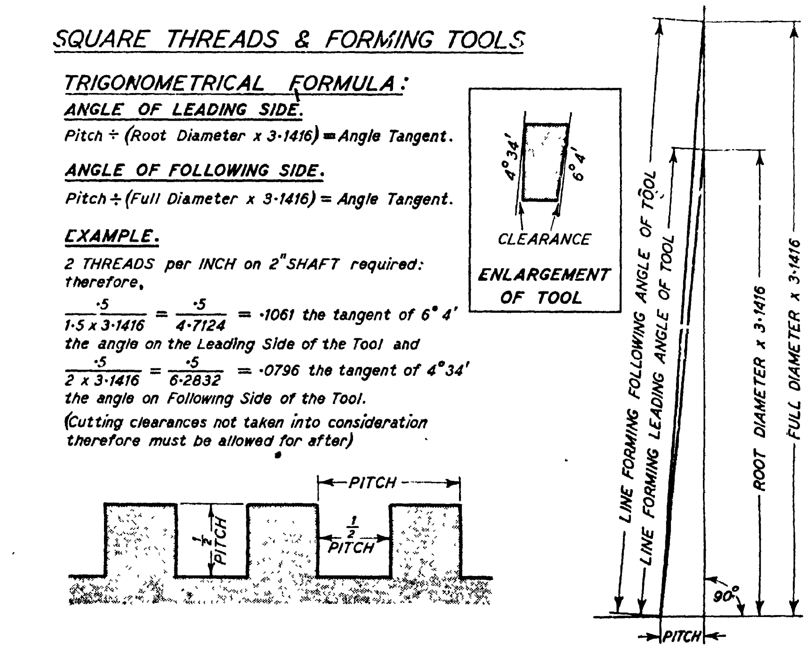


FIG. 57.—METHODS OF ARRIVING AT TOOL ANGLES FOR CUTTING SQUARE THREADS

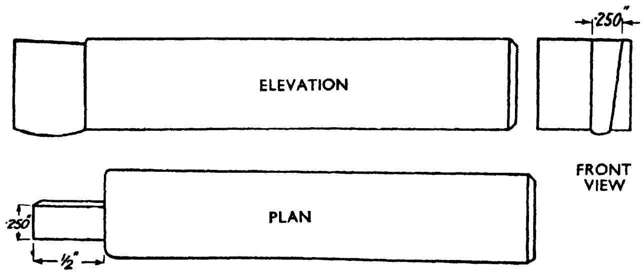


FIG. 58.—HALF-INCH PITCH SCREW-CUTTING TOOL

Tool Strains and Tempering

The front of the tool should be as short as possible, and tempered to not more than medium straw colour. This temper should be let "back" as slowly as possible, thus obviating hard places. Fig. 58 gives views of a suitable tool. The cutting point is over one side to enable the thread to be cut as close to the tommy-hole boss as possible.

Setting Tool in Holder

The tool should be as tight up to the tool holder as possible to stop any chatter. The cutting edge should be specially gauged so that it is *not above the job centre line*. This is most important, as any extra pressure on the tool point will cause a "dig-in" and consequent breakage.

Tailstock Setting

The tailstock should be set so that as little as possible of the adjustable screw is exposed. The cut being heavy, all supports should be as sturdy as possible. Excessive elongation of the tailstock screw will lead to disaster.

Starting Position of Tool

Arrange the saddle against the main body of the tailstock and the tool at the end of the job, which has already been turned down to the root diameter of the thread. This will save at least another inch with the supports.

Slide-rest Precautions

All the dovetailed slide screws should be readjusted on both the saddle and the main feed, whilst the screws on the compound rest can be tightened right up—they will not be used. The revolving compound rest should also be examined before any start is made to cut the thread.

Cutting the Thread

Lathe cross-slide screws that are marked are easy to manipulate. Frequently, however, the depth of cut is marked with chalk. In this case, a very clear mark

should be drawn each time; also the screw kept clear of any oil likely to dull the edges of the line.

The lead-screw nut can be engaged at any moment without calculation, but when withdrawing at the end of the thread, great care will have to be exercised in order not to break the tool through irregularity in withdrawal.

For such coarse threads the speed will be very slow (back gear and low pulley), but if the operator is not practised, it is as well to finish the extreme end by stopping the lathe and pulling the belt by hand.

Finishing the Thread to Size

As the job is between centres, it can be removed to try in the nut. By wiping the end marking the hard places will readily be seen.

Should it be necessary to widen the thread, the tool must be fed in from the outside after being advanced in the compound rest. The tool is not constructed to cut on the side, therefore it should not be attempted.

When the nut is fitted, the finish of the thread can be made to look neat with a square file, but it does not alter the efficiency of the cut thread, nor can the file be used to overcome errors of workmanship.

D. J. S.

DRILLS AND DRILLING

FIG. 1.—MULTI-SPINDLE DRILLING MACHINE (*Ford Motor Co., Ltd.*)

THE drill is, next to the hammer, the most widely employed tool in workshops dealing with metal, wood, and many other substances. In this article the use of drills for metal only will be dealt with.

Flat Diamond-point-type Drill

The advent of the twist drill marked a most important advance. Up to the introduction of this drill, the only form of drill used for metal was the flat diamond-point type shown in Fig. 6. This had several serious drawbacks. It was not possible with this type of drill to ensure accuracy either in the position of the hole in the work, true circularity, or the axis of the hole following a straight line. Also, the drilling of deep holes presented difficulties: the drill did

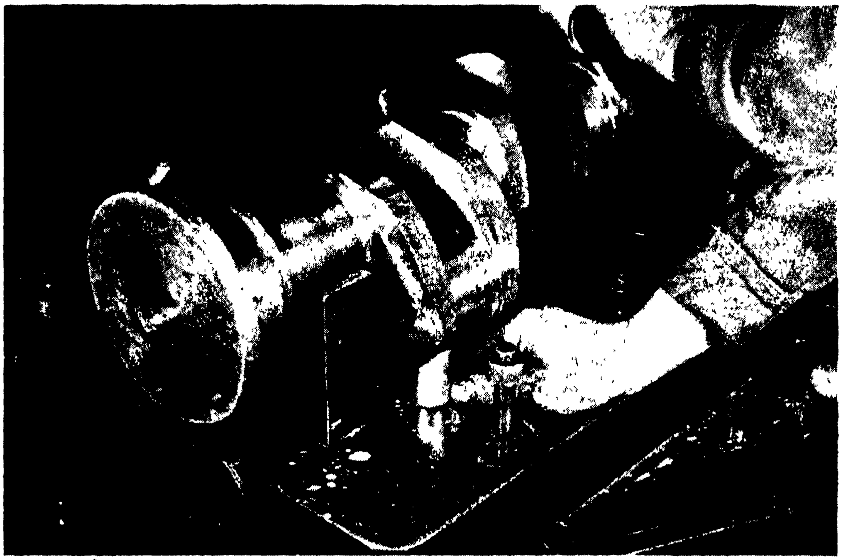


FIG. 2.—DRILLING OILHOLES IN A CRANKSHAFT (1)
The adjusting piece being put in position. (*A.E.C., Ltd.*)

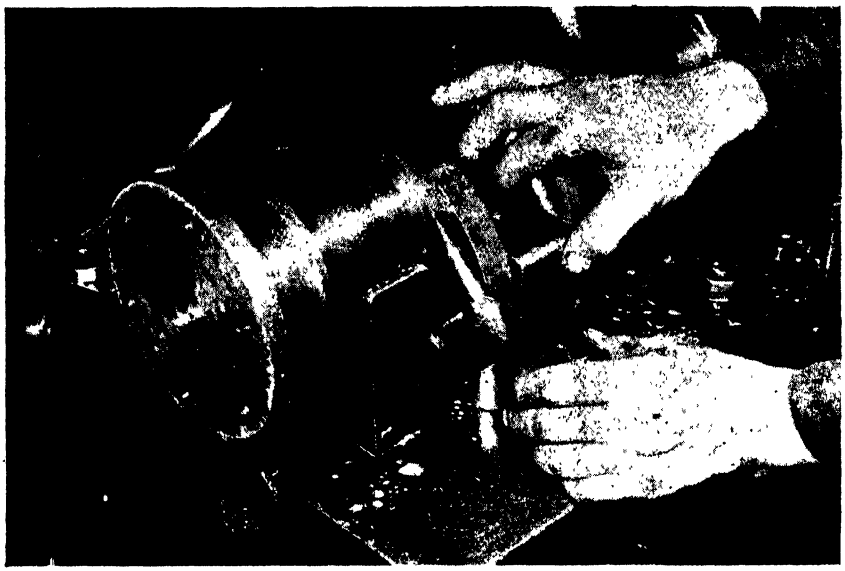


FIG. 3.—DRILLING OILHOLES IN A CRANKSHAFT (2)
The template to mark off the oilholes. (*A.E.C., Ltd.*)

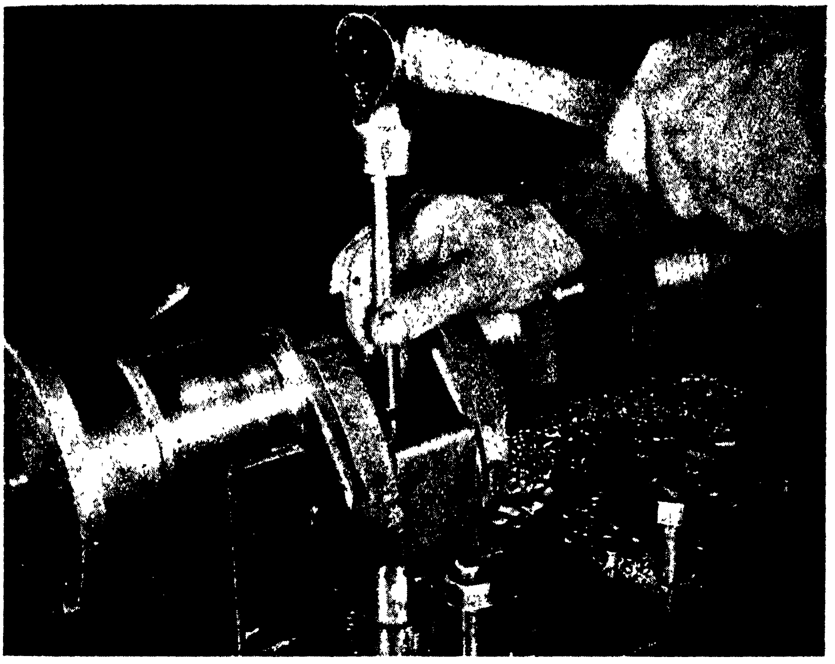


FIG. 4.—DRILLING OILHOLES IN A CRANKSHAFT (3)
Hammering the centre punch through a template hole. (*A.E.C., Ltd.*)

not remove its own chips or cuttings and had to be periodically withdrawn and the hole cleared. The drill also acted more as a scraping than a cutting tool.

While it was possible to grind a relief groove behind the cutting edge to give it "rake," this was limited by the necessity of preserving the strength of the edge, as the drill point could not be made too thick or the pressure required to feed it into the cut would be very great. Another grave defect in connection with the use of this drill for accurate work was that every time it was sharpened the diameter was affected.

The flat drill is still used on work where accuracy is not of the first importance, such as structural steel work, and is then generally used in a ratchet brace.

Twist Drills

The twist drill is not a forged article like the flat drill, used in its forged state apart from grinding the edge, but an accurately machined job. Provided that it is properly ground, it can be relied upon to produce holes true to 0·001 in. in ordinary commercial work in the position required and parallel to the axis, the long "barrel" of the drill acting as a guide and so keeping the centre line of

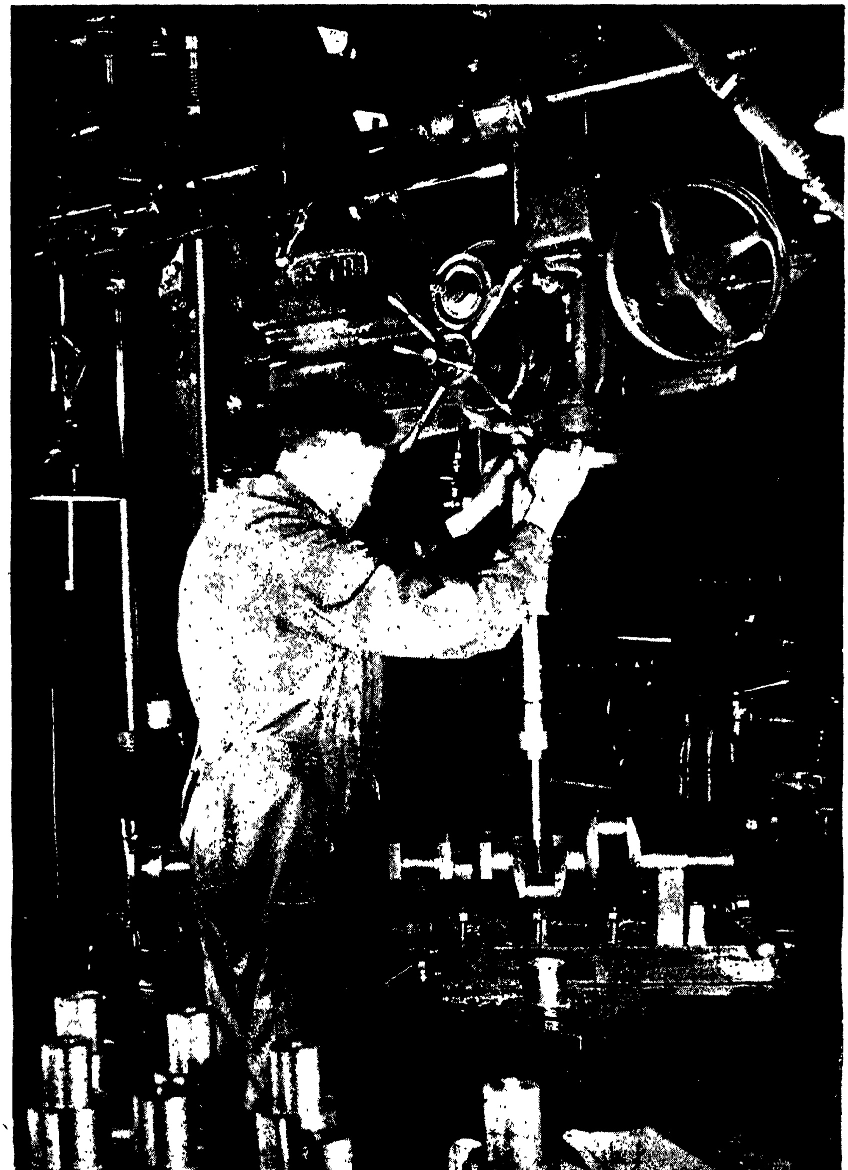


FIG. 5.—DRILLING OILHOLES IN A CRANKSHAFT (4)
The oilholes being drilled by a drilling machine. (*A.E.C., Ltd.*)

the hole true. The spiral flutes allow of a sharp cutting edge being obtained, and the diameter of the drill is not affected by sharpening any number of times; in fact, until the drill is ground right away. The spiral flutes act as conveyors and remove the cuttings, so that, except in holes many times the diameter of the drill in depth, it is not necessary to withdraw the drill to clear the hole.

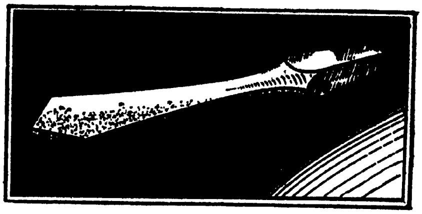


FIG. 6.—DIAMOND-POINT FLAT DRILL WITH SQUARE SHANK

Twist drills are supplied in high-speed or carbon steels. The price of the former is considerably above that of the carbon-steel drills, but is justified by the higher output possible by their use and the less frequent need of compared with carbon-steel drills.

Types of Twist Drills

The main types of twist drills are illustrated in Figs. 7 and 8. These have been reproduced from B.S. 328, 1950, published by the British Standards Institution, 24–28, Victoria Street, London, S.W.1.

For general work twist drills are supplied in several types as follows:

Straight shank, the shanks being parallel and of the same diameter as the size of the drill.

Taper shank, the shank being a standard Morse taper, varying in No. of taper with the diameter of the drill.

Drills with ½-in. diameter parallel shank.—These are supplied in two lengths, the same as that of standard length taper-shank drills, the "short length," the drill portion being about half the length of standard. The shank length in each case is the same, 2½ in. These types are all supplied in two forms—Increase Twist or Constant Angle.

Increase Twist

In increase twist drills the flutes or grooves are made wider towards the top of the drill, giving increased area and preventing clogging by chips when drilling deep holes.

Constant Angle

In the constant-angle drills, the increased area of the groove is obtained by a gradual variation in the angle of the milling cutters to the axis of the drill. The rotation of the drill is kept uniform so that the groove is of constant pitch. This widens the groove towards the shank of the drill and compensates for

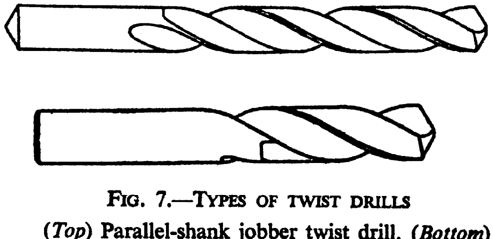


FIG. 7.—TYPES OF TWIST DRILLS

(*Top*) Parallel-shank jobber twist drill. (*Bottom*) Stub drill. (*British Standards Institution.*)

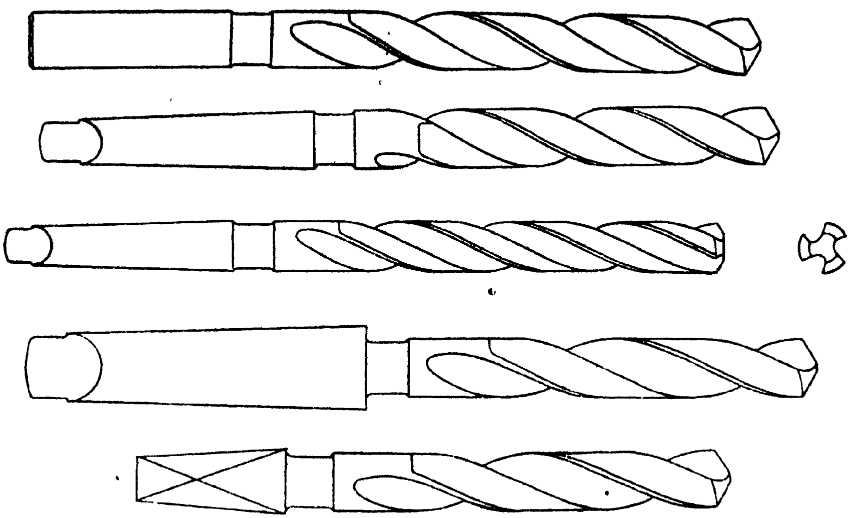


FIG. 8.—TYPES OF TWIST DRILLS

(*Top to Bottom*) Parallel-shank long-series twist drill. Taper-shank twist drill. Taper-shank three- or four-twist drill. Oversize taper-shank twist drill. Taper square-shank twist drill for ratchet braces. (*British Standards Institution.*)

the reduction in area which results from its diminishing depth. With both systems, the more the groove is enlarged towards the shank, the more the torsional strength of the drill is impaired. With the constant-angle drills, however, the contour, angle, and area of the grooves at all parts of the length are proportioned to combine the maximum torsional strength, the most efficient chip clearance, and the best form of cutting lip. The price of standard length drills, parallel or taper shanks, is the same.

"Jobber's Length"

The smaller sizes of twist drills up to ½-in. diameter are supplied in short lengths, parallel, and are known by the term "Jobber's Length." These form a cheap type of drill for general work, and are sold in inch, millimetre, letter, and wire-gauge sizes.

As an example of the length, a ¼-in. diameter standard length drill, parallel or taper shank, is 6⅛ in. long (Morse).

A jobber's length drill of the Morse diameter is 4 in.

Special Types of Twist Drills

Twist drills with square taper shanks to fit ratchet braces and carpenters' braces are regular stock items.

Hollow Twist Drills

Hollow twist drills have a hole through the shank connecting with the grooves. The drill shank is parallel, but reduced in diameter to allow it to be sweated into a tube, or it can be screwed and the tube tapped out to screw on it. This allows of very long holes being drilled; the tube is really an extension of the shank of the drill, and the chips and lubricant escape through the tube. The spiral or twist of the grooves is very coarse, only making about one half turn in the length of the drill. The "lands" have shallow channels cut in them to convey the lubricant to the point of the drill.

These drills are available from ⅝ in. to 3 in. diameter. As the tube forms the guide for the drill, it should be the same outside diameter as the drill. Twist drills are also supplied with lubricant holes through the solid metal of the drill to convey the lubricant to the cutting edges. There are two holes, one down each "land" the whole length of the drill and communicating with a hollow shank. These are generally used in screw or chucking machines.

TABLE OF SPEEDS AND FEEDS OF DRILLS

CARBON STEEL

Dia. in.	Revolutions per Min. Wrought Iron and Steel	Cast Iron	Brass	Dia. in.	Revolutions per Min. Wrought Iron and Steel	Cast Iron	Brass
1/16	1,833	2,320	3,667	1 1/4	67	107	183
1/8	917	1,160	1,833	1 5/16	64	102	175
3/16	611	773	1,222	1 3/8	61	97	167
1/4	458	580	917	1 7/16	58	93	159
5/16	342	465	733	1 1/2	56	89	153
3/8	285	386	611	1 9/16	54	86	147
7/16	244	331	524	1 5/8	52	82	141
1/2	214	290	458	1 11/16	50	79	136
9/16	176	238	407	1 3/4	48	76	131
5/8	159	214	367	1 7/8	45	71	122
11/16	144	194	333	2	42	67	115
3/4	132	178	306	2 1/8	40	63	108
13/16	112	165	282	2 1/4	38	59	102
7/8	105	153	262	2 3/8	36	56	96
15/16	98	143	244	2 1/2	34	53	92
1	90	134	229	2 5/8	32	51	87
1 1/16	80	126	216	2 3/4	30	49	83
1 1/8	75	119	204	2 7/8	28	47	80
1 3/16	71	113	193	3	26	45	76

HIGH-SPEED STEEL

Dia. in.	Revolutions per Min. Wrought Iron and Steel	Cast Iron	Brass	Dia. in.	Revolutions per Min. Wrought Iron and Steel	Cast Iron	Brass
1/8	1,832	2,440	Periphery Speed 100 to 140 feet per minute.	1 1/8	204	255	Periphery Speed 100 to 140 feet per minute.
3/16	1,221	1,627		1 3/16	193	242	
1/4	916	1,220		1 1/4	183	229	
5/16	733	976		1 5/16	174	219	
3/8	611	813		1 3/8	166	209	
7/16	523	697		1 7/16	160	199	
1/2	458	610		1 1/2	153	191	
9/16	407	510		1 9/16	143	184	
5/8	366	459		1 5/8	138	176	
11/16	333	417		1 3/4	127	164	
3/4	305	383		1 7/8	112	153	
13/16	282	353		2	104	143	
7/8	262	328		2 1/8	95	126	
15/16	244	306		2 1/4	89	118	
1	229	287		2 3/8	80	112	
1 1/16	215	270		2 1/2	76	106	

FEED PER REVOLUTION

Carbon-steel Drills in.	in.	High-speed-steel Drills in.
0·005	1/4	0·006
0·009	1/2	0·010
0·012	1	0·015
0·015	2	0·020

Straight-fluted Drill

A third type of drill which is used to some extent is the straight-fluted drill. This is used in drilling some non-ferrous metals. It is supplied in the same

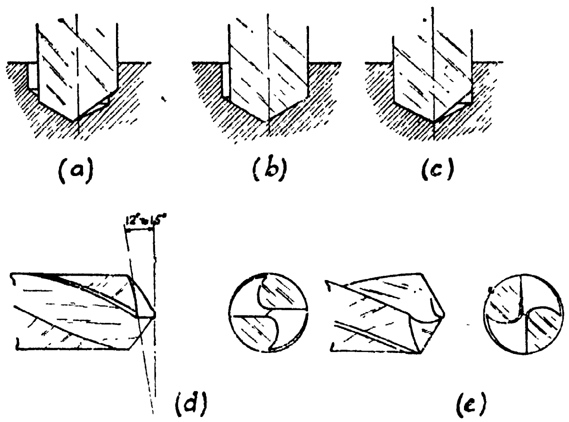


FIG. 9.—POINTS IN CONNECTION WITH DRILL GRINDING

(*a*) and (*b*) Drill ground with unequal angles, tending to cut a hole larger than own diameter. (*c*) One lip of drill alone cutting due to unequal grinding. (*d*) Showing angle of rake with correctly ground drill. (*e*) Thinning of point.

lengths and shanks as twist drills, either carbon or high-speed steels, since the prices are the same as for twist drills.

Speeds and Feeds

The most important points in the use of drills are the speed and feed, especially the former. Small-diameter drills require to be run at a high speed and more drills are broken by this point being neglected than anything else. In some cases, such as the use of small drills in braces and "breast" or hand drills, the requisite speeds cannot be obtained, but for all accurate and production work the correct speeds should be adhered to. The Table on page 279 gives the speeds and feeds of drills. It will be noted that these are considerably greater with high-speed-steel than with carbon-steel drills.

Lubrication

For use with steel or wrought iron, ample lubrication must be employed. Generally soap suds or one of the valuable cutting oils are used. For cast iron the drill is run dry. For ordinary work on most non-ferrous metals the drills are also run dry, but for fast work suds can be used for brass, bronze, aluminium, etc. Copper requires cutting fluid and suds or one of the proprietary cutting oils can be used. For cases where copper is very extensively employed, special twist drills are available with a 40° helix (closer pitch than the standard twist drills). Copper can, however, be drilled quite satisfactorily with the standard twist drills or the straight-fluted drill. The supply of lubricant during drilling in copper should be ample. For drilling hard or tough steels a heavier cutting lubricant should be employed, such as lard oil or a brand of cutting oil sold for this purpose.

Grinding Twist Drills

The twist drill is a precision tool, and to grind it accurately requires a special twist-drill grinder, or grinder attachment which can be fitted to the usual tool grinder, emery, or carborundum wheel.

These grinders are so arranged that the drill is presented to the wheel at the

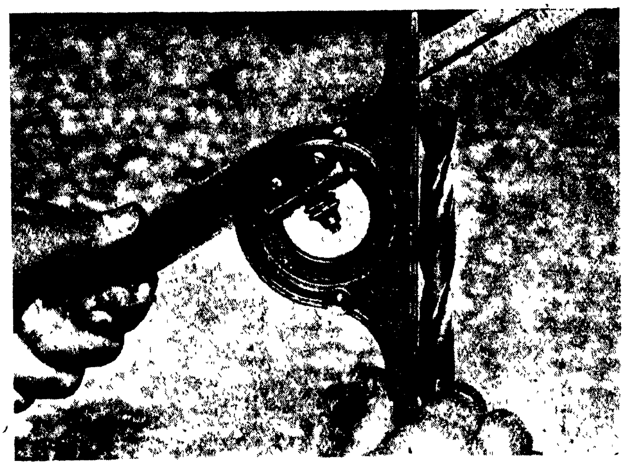


FIG. 10.—THE CORRECT CUTTING ANGLE

The protractor shows an angle of 121°, the cutting angle thus being 59°. Drill is rotated to test both angles.

correct angle to ensure the correct cutting rake, and as the drill is rotated in the holder both cutting angles are the same and the drill is ground true to the centre line.

For accurate work accurate grinding is essential, and while many twist drills are ground "by hand," it takes very considerable skill and practice to get a result even approximately correct; and if a number of hand-ground drills are examined in any workshop and compared with machine-ground drills, they will be seen to leave much to be desired.

The most common fault with hand-ground drills is that the two cutting angles are dissimilar. This means that the centre of the drill is moved over and the drill will not cut its correct size. Also one cutting edge will be doing all or most of the work, which frequently results in breaking the drill. The rake is also seldom the same on both cutting angles of hand-ground drills. Fig. 9 shows some of the defects frequently found in hand-ground drills. It will be seen in (*a*) and (*d*) that owing to the angles being unequal, the drill is tending to cut a hole larger than its diameter.

In (*c*), Fig. 9, it will be clearly seen that one side of the drill is not cutting, throwing uneven torque on the drill and probably causing fracture. The drill should be ground to an angle of 59° (Fig. 10). It is revolved to bring both edges under the blade of the gauge to ensure that they are the same. The drill should then be turned through approximately 90° to show the rake (Fig. 11), and this should be equal for both cutting angles. When this test is not applied to hand-ground drills, the rake is often quite absent, and no amount of pressure will cause the drill to cut, and it will probably crush under the load.

For copper it is often an advantage to grind off the sharp edge of the cutting lip, giving it an edge like a flat drill, an extra clearance or rake being given to the edge or a radius ground behind the cutting edge. This will prevent "digging in" on soft materials like annealed copper.

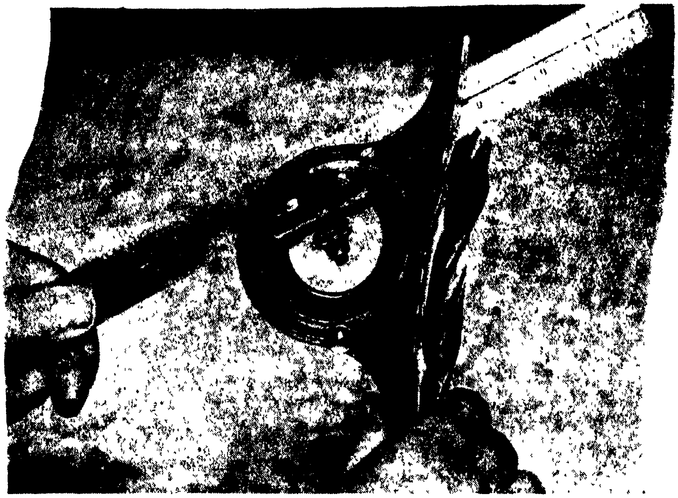


FIG. 11.—SHOWING RAKE

Note distance between drill edge and protractor. Drill is rotated to test rake of other angle.

In grinding a twist drill by hand, the drill should be held at as near the correct angle, 59°, as possible to the face of the stone with the shank end of drill dropped. The drill is revolved to bring the cutting edge to the face of the wheel, and when an edge has been ground, the other should be brought up to the wheel. In Fig. 12, the drill is being turned anticlockwise to grind the edge applied to the wheel. In Fig. 13 the end of the rotation is shown, the cutting edge having been rotated on to the stone. Note that there are two angles to be observed in holding the drill to the stone, the first to give the cutting angle of

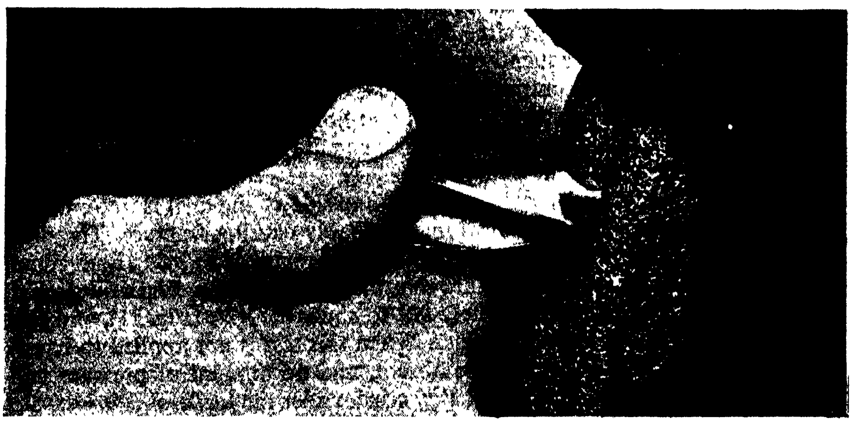


FIG. 12.—GRINDING DRILL—FIRST POSITION

The drill is held against face of stone with cutting edge horizontal and at an angle of 59° to the stone. Stone rotates towards operator. The shank end of the drill should drop more than shown in the illustration.

59°, and the other, by dropping the shank end of the drill, to give the necessary clearance or rake. The drill should be frequently tested against the gauge and the grinding continued until both sides are identical in angle and rake.

One common trouble is turning the drill too far in grinding one angle, thus bringing the cutting edge of the other angle, near the point, on to the stone and grinding it off. While it is worth while acquiring experience in grinding twist drills by hand, it should be noted that this would not be tolerated in any engineering works where accuracy is required: the drills would be properly ground in the tool room or proper drill-grinding equipment would be available.

Ratchet-brace Drills

In ratchet braces no question of running a drill at its correct speed and feed arises; the only point is to get the hole drilled, the ratchet brace only being

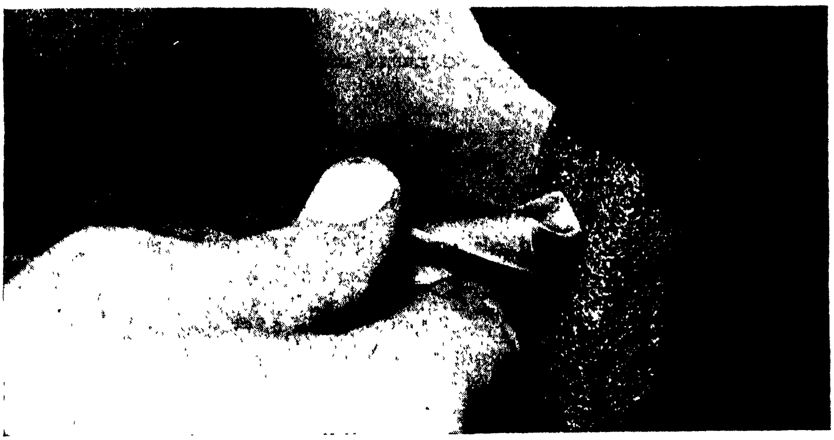


FIG. 13.—GRINDING DRILL—FINAL POSITION

The drill is in the final position after producing rake. Showing how much the drill is turned down towards the rear end. Note also the slant of the drill.

used because other and more efficient means are either unobtainable or cannot be brought to the job.

Flat diamond-point drills (Fig. 6) are frequently used, being cheap, and readily reforged and reground after breakage. Twist drills are, however, often used in ratchet braces and are made with square shanks. Some ratchet braces have a ½-in. parallel hole instead of a square hole and use the short-length ½-in. shank twist drills, the drill being secured by setscrew in the chuck of the ratchet brace.

Hand Braces or Breast Drills

These drills, as the name implies, are worked by hand, the pressure being imparted by pressure from the breast of the operator (Figs. 15 and 16). The

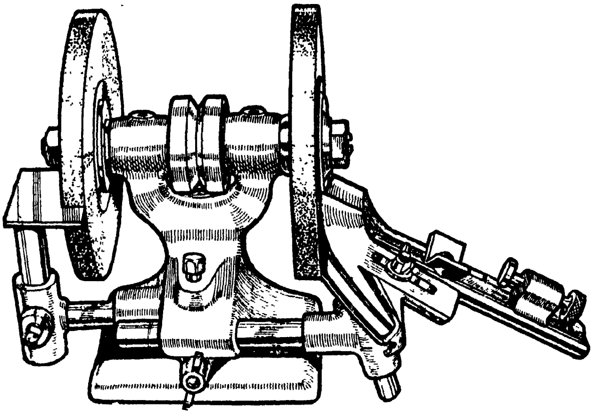


FIG. 14.—TWIST-DRILL GRINDER TAKING DRILLS FROM $\frac{1}{16}$-IN. DIAMETER

drills are always fitted with three-jaw self-centring chucks, and in the largest sizes take up to $\frac{1}{2}$-in. diameter drills, or a larger drill with $\frac{1}{2}$-in. parallel shank can be used.

The larger drills are usually fitted with two speeds, but even with this the faster speed does not enable the smaller drills to be run at their correct speed. The parallel short-length or jobbers' drills are chiefly used, as holes of any length are not often required to be drilled in metal by breast drills. The chief difficulty in the use of breast drills is to hold them square in each direction with the work (Fig. 16). If the job allows, two small engineers' squares can be stood on the work at right angles to each other and as close to the drill as practicable. This will enable the operator to see if the drill is square with the job. Otherwise it is as well to get another person to "sight" the drill when starting the hole.

The modern good-quality breast drill is a very high-class tool, practically indestructible: the operator cannot exert enough force to damage it, and the size of drill generally used would succumb before any damage could happen to the brace. In the best breast drills the gears are enclosed and run in oil; and as well as the two speeds and a free position, there is a locking device to the spindle which allows the chuck to be slackened or lightened without having to hold the handle.

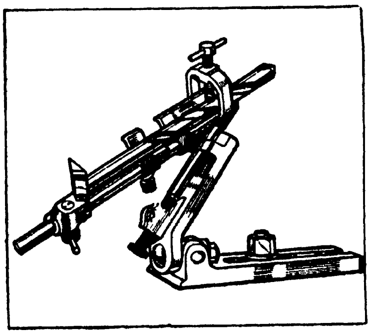


FIG. 14A.—TWIST-DRILL GRINDING ATTACHMENT TO FIT TO ANY EMERY WHEEL OR GRINDSTONE

Takes drills up to 1-in. diameter.

Portable Electric Drills

These are available in a large number of types and sizes, from the small "pistol" type of hand drill with a capacity of $\frac{3}{16}$-in. diameter in steel to the largest high-power types weighing up to $\frac{3}{4}$ cwt. with a capacity of 2 in. in steel. With the smaller types held and operated by hand, the same difficulty arises as with breast drills—of holding the drill square with the work.

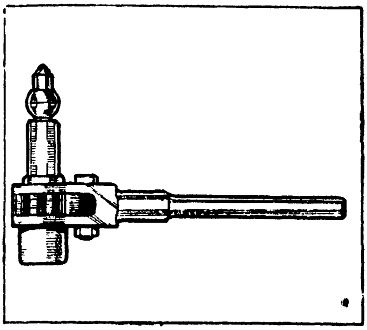


FIG. 14B.—RATCHET BRACE WITH CHUCK ARRANGED TO TAKE EITHER TAPER- OR SQUARE-SHANK DRILLS

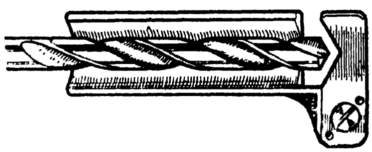


FIG. 14C.—A SIMPLE DRILL-GRINDING GAUGE TAKING DRILLS UP TO ¾-IN. DIAMETER

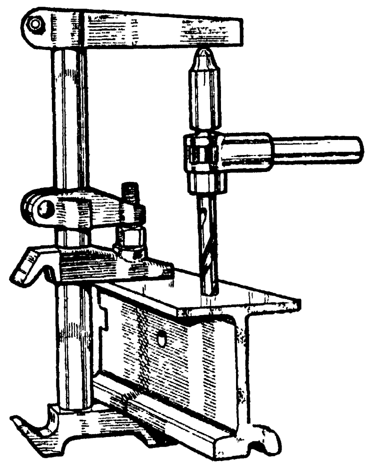


FIG. 14D.—RATCHET BRACE WITH TWIST DRILL, DRILLING RAIL

The larger types are used with a drilling pillar or cramp, as used with hand ratchet braces, so the drill can be squared to its work.

Speeds

The weight of the drill is considerable, and the operator is prone to let it sag while drilling and break the drill. With these drills, the speed available is generally ample for the smaller sizes of drills and too great for the larger sizes. Some makers overcome this by fitting chucks which will not accommodate any drills larger than those for which the speed of the machine is suitable.

Cables

Up to ½-in. diameter capacity, these drills are fitted with three-jaw self-centring chucks and above that with Morse taper sockets. The cables of these machines are liable to get very rough treatment and should be efficiently armoured. The usual rules relating to the use of portable electric tools should be rigidly observed, as many accidents have occurred by their non-observance. Most makers supply the drills fitted with 3-core armoured cab-tyre flex and three-pin plugs forming a safe earthing circuit.

DRILLING MACHINES

The modern drilling machine has developed chiefly along the lines of specialised machines, multiple-spindle types, deep-drilling machines, where, in

some cases, the drill is stationary and the work revolves. The ordinary plain drilling machines, by which is meant the ordinary types of sensitive, vertical and radial, which deal with a varied run of work, have altered very little in general design over quite a long period.

Main Features

The main features which have been developed in modern machines of these types are better, more centralised, and easier control, better balancing of spindles in the higher-speed models, direct

FIG. 15.—THE CORRECT WAY TO USE A HAND DRILL

driving, and the use of modern alloys both in the cast-iron and steel parts of the machines.

The advent of the high-speed steel drill called for higher spindle speeds, but generally the older types of drilling machines were quite robust enough to stand the extra strain of these drills, but could not provide the speeds required to take advantage of the extra output possible by their use.

Bench-type Sensitive Drills

The sensitive drilling machine, the term meaning the application of the drill pressure by hand through a short lever, is now made

FIG. 16.—THE INCORRECT WAY TO USE A HAND DRILL

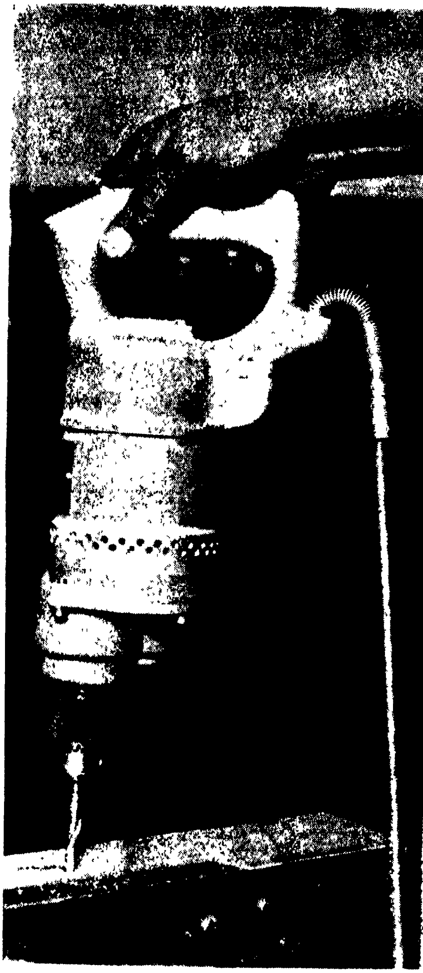


FIG. 17A.—HOW NOT TO USE A PORTABLE ELECTRIC DRILLER

The cable is far too short. If the cable is of insufficient length to reach the work comfortably, the constant strain is liable to result in broken connections at the switch handle.

FIG. 17B.—USING A CABLE REEL WITH A PORTABLE ELECTRIC DRILLER

If it is possible, a cable reel should be used to prevent cable breakage. This is specially suitable where long lengths of cable are in use.

in many types to suit the class of work dealt with. Fig. 18 shows a plain, bench-type, sensitive drilling machine for general work. The capacity is $\frac{1}{2}$-in. diameter, and the maximum spindle speed 600 revs. per minute. A ball thrust is fitted to the spindle and the weight of the spindle is spring-balanced. The jockey pulleys are adjustable to allow of stretch in the belt to be taken up. A

depth gauge is fitted, and will be seen at the top of the spindle sleeve. This machine has cast-iron bearings to the spindle, but in some makes ball bearings are fitted.

Fig. 19 shows a machine of similar capacity, but direct driven, the maximum spindle speed in this case being 1,200 revs., the motor being 0·5 h.p. The distance from the centre of the spindle to the column is 6 in. In some cases the head is adjustable vertically on the column, giving a greater distance below the drill.

Direct-driven Drills

Another type of sensitive drill is shown in Fig. 20, the motor being mounted directly over the spindle. In this machine there are four changes of speed available by levers on the head, and change wheels are supplied by which twelve changes of speed can be obtained, giving a range from 200 to 3,600 revs. per minute. The capacity is 1-in. diameter. Any usual height of column is available.

Multiple Sensitive Drilling Machines

Multiple sensitive drilling machines with each spindle directly driven by electric motor are now in considerable use.

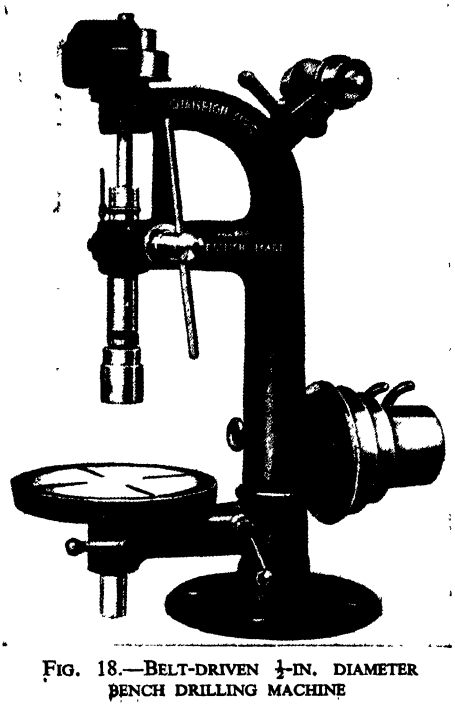


FIG. 18.—BELT-DRIVEN ½-IN. DIAMETER BENCH DRILLING MACHINE

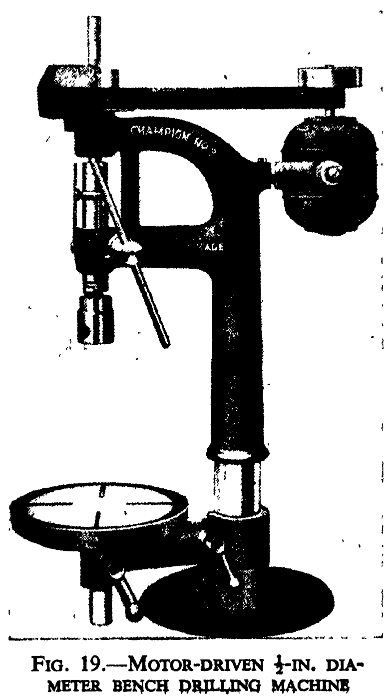


FIG. 19.—MOTOR-DRIVEN ½-IN. DIAMETER BENCH DRILLING MACHINE

With these multiple-spindle drills it is usual to have different speed ranges. In one type of machine, for example, the first spindle is ungeared, and has a range of speeds from 445 to 1,455 revs. The second spindle is geared and has speeds from 50 to 300 revs. The third spindle is also geared with eight speeds, ranging from 100 to 550 revs. The capacity in mild steel is, first spindle $\frac{3}{4}$ in., second $1\frac{1}{4}$ in., third $1\frac{1}{8}$ in. The motors fitted are of the pole-changing type, and all bearings are fitted with grease nipples for grease-gun lubrication. Another machine of similar type has a V-belt drive, all enclosed, the speed variations being obtained by simply slipping the belt on to the desired cones.

Multiple-spindle machines are available up to any number of spindles required.

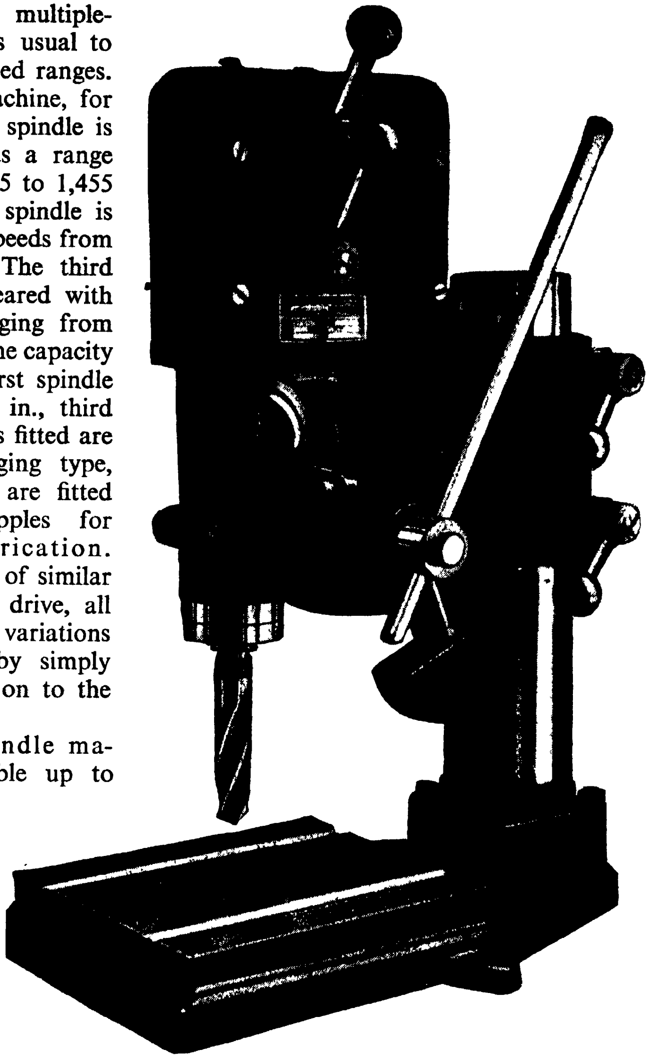


FIG. 20.—ELECTRIC DIRECT-DRIVEN SENSITIVE BENCH DRILL, 1-IN. CAPACITY (*C. H. Joyce, Ltd.*)

High-speed Vertical-pillar-type Machines

A modern high-speed vertical-pillar-type machine is shown in Fig. 21. This is driven by a 5-h.p. motor, and has a capacity in mild steel of 2 in.

Twelve speeds are available between 60 and 1,500 r.p.m. for full power drilling from the solid, and five speeds from 15 to 60 r.p.m. with reduced power for reaming, facing, tapping, etc. The speeds are changed by means of two levers, one at the front and the other at the left-hand side of the saddle, the speed in

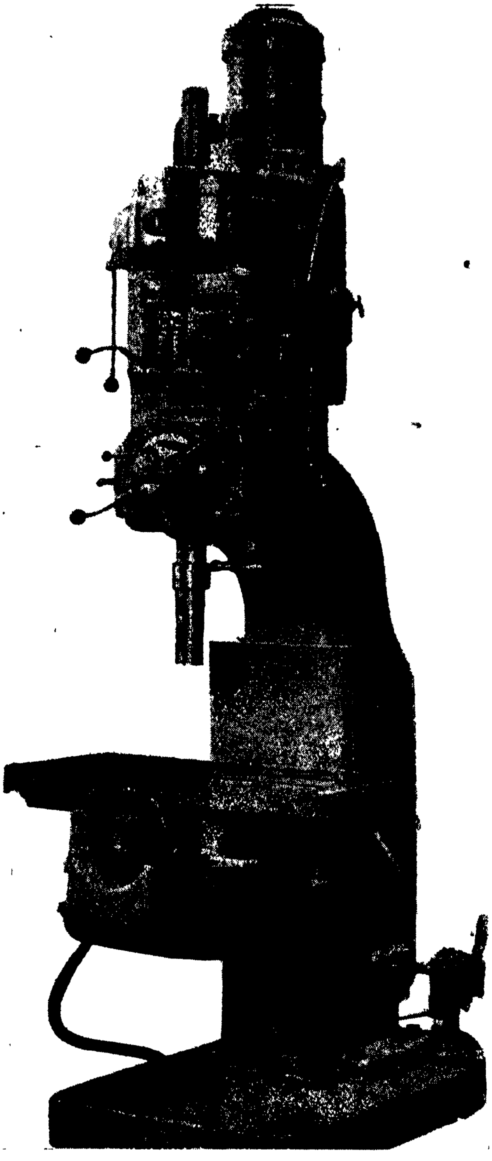


FIG. 21.—THIRTY-INCH VERTICAL DRILL
(*J. Archdale & Co., Ltd.*)

use and the size of the drill and cutting speed for various materials being directly indicated. The spindle is started, stopped, and reversed by a single lever operating a control switch on the right-hand side of the head. This lever is also used for the "inching" device which enables speed changes to be quickly and easily carried out. Six rates of automatic feed are provided, and a safety slipping clutch is incorporated in the feed drive to guard against the possibility of damage to the machine in case of overload.

Heavy-duty Vertical Drilling Machines

Fig. 22 shows a machine designed for heavy-duty drilling of holes up to 3 in. diameter from the solid in mild steel, at a penetration rate of $1\frac{1}{4}$ in. per minute. This is a 32-in. machine, driven by a 10-h.p. motor.

The range of spindle speeds is

15–370 r.p.m., and twelve speeds are available through levers at the left-hand side of the head. Six rates of automatic feed are obtained through the star wheel at the right-hand side of the head.

In these machines, where the stresses are severe, very high quality materials are necessary. The spindles are of nitralloy steel, the clash gears of case-hardened nickel-chrome steel, and the constant-mesh gears of heat-treated 100–120 tons steel. The sliding-gear shafts are of high-tensile steel with ground splines. The spindle is carried in phosphor-bronze bearings.

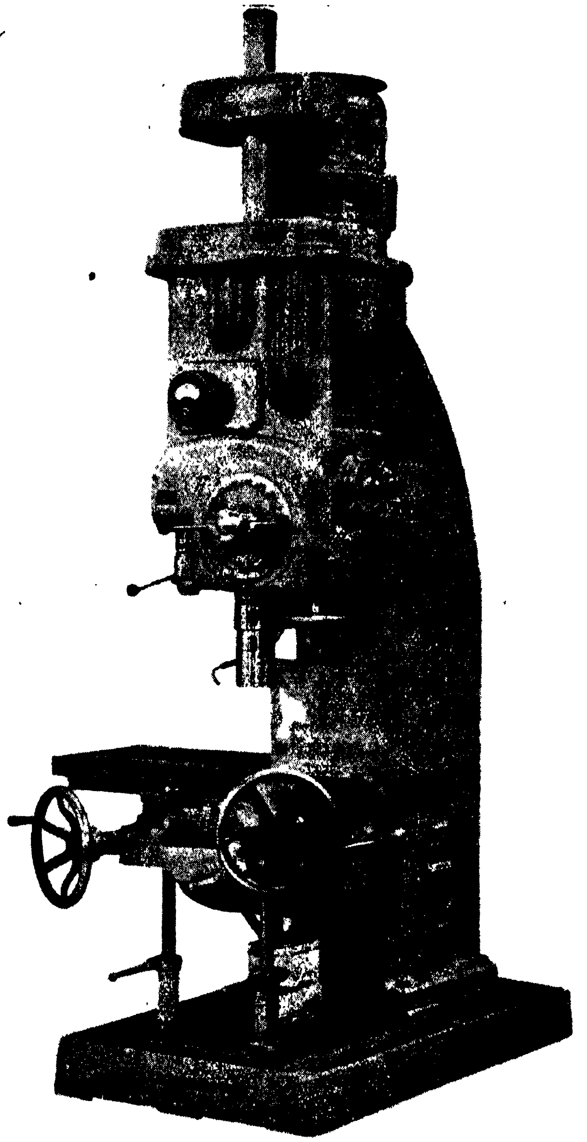


FIG. 22.—HEAVY-DUTY VERTICAL DRILL
(*J. Archdale & Co., Ltd.*)

Radial Drilling Machines

Modern radial drilling machines incorporate the latest practice of direct drive and high-tensile steels and alloys in their construction. Multiple all-geared speed and feed boxes are generally fitted,

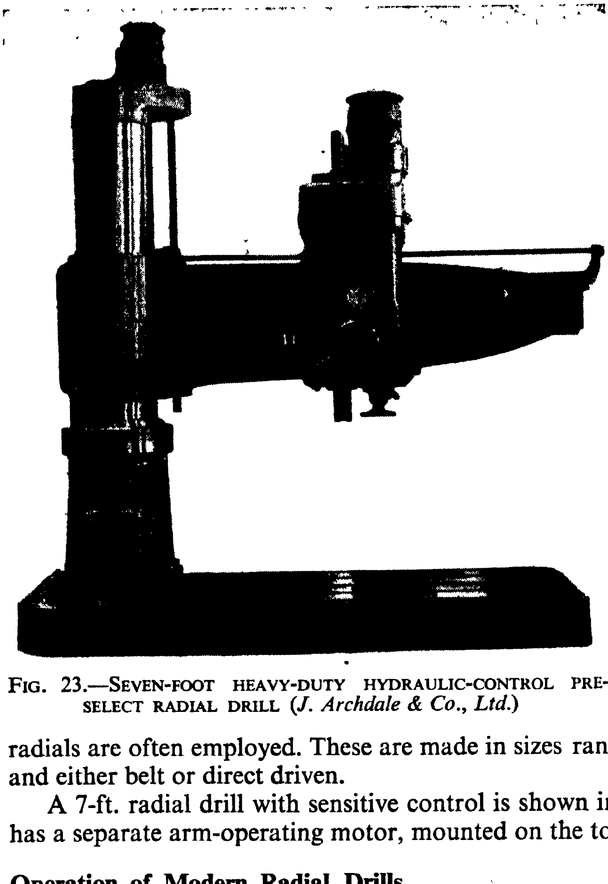


FIG. 23.—SEVEN-FOOT HEAVY-DUTY HYDRAULIC-CONTROL PRE-SELECT RADIAL DRILL (*J. Archdale & Co., Ltd.*)

and in the larger types of machines independent electric motors are fitted to raise the arm and traverse the saddle along the arm.

Separate box beds are now available in several forms, which can be selected to suit the work on hand.

For modern girder work direct-driven radial drills with arms to 8 ft. are available. Usually only one speed and one rate of feed are provided on these machines, but any variation of this is available.

For boiler and other work, wall radials are often employed. These are made in sizes ranging from 4 ft. to 8 ft., and either belt or direct driven.

A 7-ft. radial drill with sensitive control is shown in Fig. 23. This machine has a separate arm-operating motor, mounted on the top of the column.

Operation of Modern Radial Drills

The design of and materials used in the spindle gear-box and feed motion of this machine are fair examples of the best modern practice.

The spindle is of 0·5 per cent. carbon high-tensile steel, of solid six-spline form ground on the splines. It runs in a steel sleeve of the same material, the feed rack being cut integral with the sleeve. The spindle is mounted in a hard phosphor-bronze bearing at the bottom and a white-metal bearing at the top of the sleeve, ball thrust bearings also being provided at top and bottom. Twenty-two spindle speeds are provided and selected by a single lever, as shown. The speed in use is directly indicated, also the size of drill and cutting speed for various materials. All driving gears are ground on the tooth profile, clash gears are of nickel-chrome steel case hardened, and constant-mesh gears of oil-hardened nickel-chrome steel. Shafts are of 0·5 per cent. carbon high-tensile steel, and shafts with solid pinions of heat-treated 75–85 tons steel. All sliding

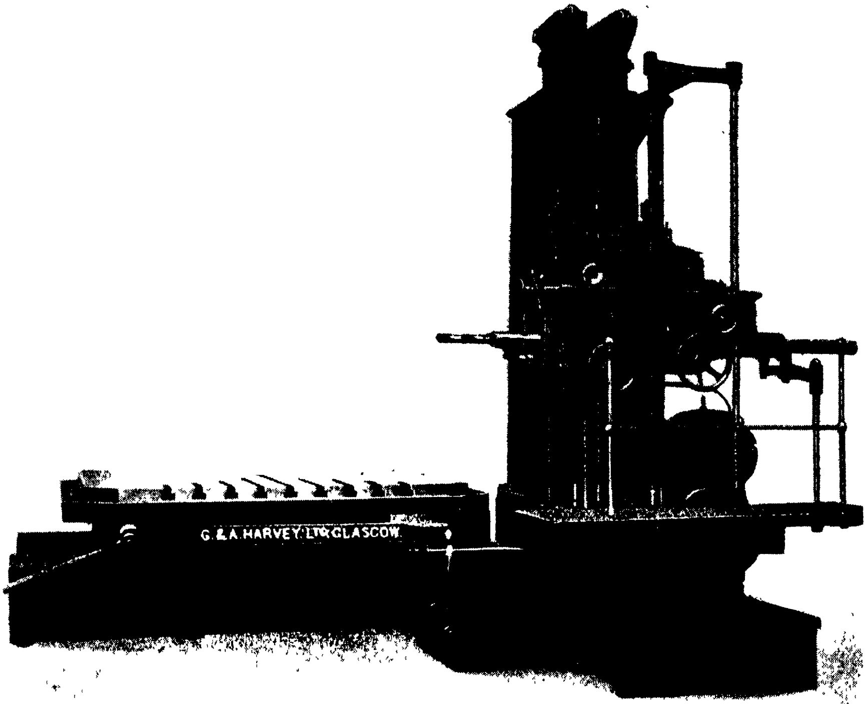


FIG. 24.—THREE-AND-A-HALF-INCH SPINDLE HORIZONTAL DRILLING MACHINE WITH SLIDING TABLE
(*G. & A. Harvey, Ltd.*)

gearshafts are of solid six-spline form ground on the splines. Main driving shafts run in ball bearings. The spindle is stopped, started, and reversed by electric switch. Eighteen rates of automatic feed are provided. The feed gears and the worm feed are hardened, the thread of the feed worm being ground. The feed-worm wheel is of hard phosphor bronze and runs in oil. The feed-rack pinion shaft is of chrome-vanadium steel, the pinion being solid with the shaft. The feed is engaged by the same hand wheel which provides the spindle quick-hand traverse. Fine hand feed is also provided, the fine-feed handwheel being stationary when the automatic feed is engaged. Sensitive lever feed by "pull-forward" lever is also provided.

Portable Radial Drills

The portable radial drill has been developed for use in circumstances where it is often more convenient to take the machine to the work. A typical machine is described below. This is a portable radial drill with universal motion, allowing holes to be drilled at any angle. In these machines the arm slides through the saddle, which is mounted on the column. Direct drive is employed.

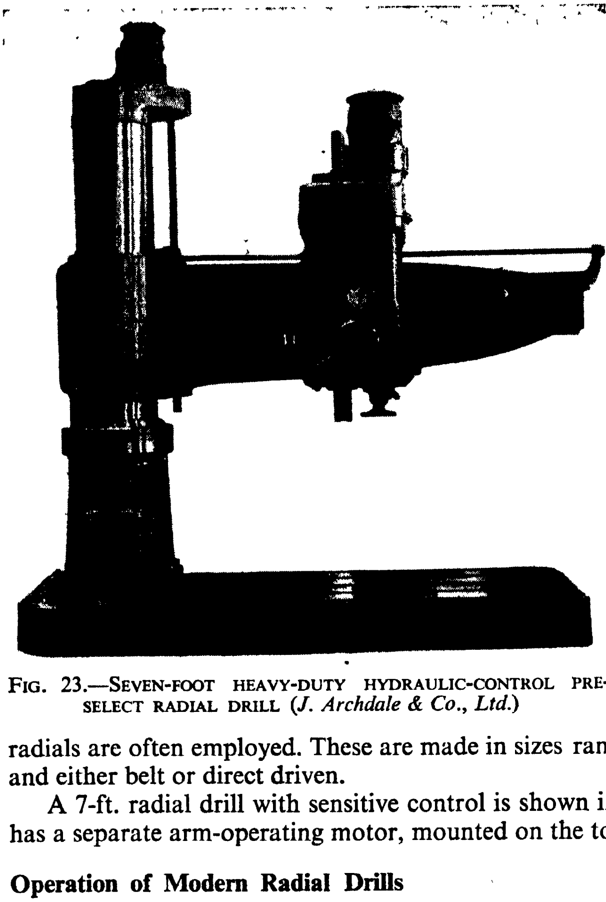


FIG. 23.—SEVEN-FOOT HEAVY-DUTY HYDRAULIC-CONTROL PRE-SELECT RADIAL DRILL (*J. Archdale & Co., Ltd.*)

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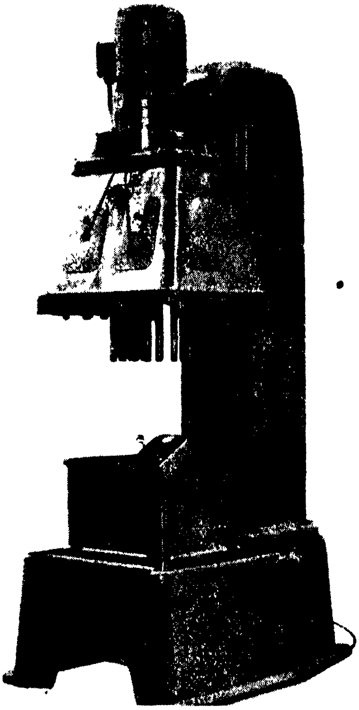
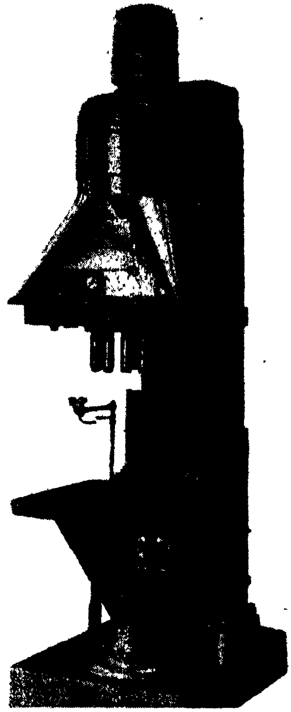




FIGS. 27 AND 28.—TYPES OF UNIVERSAL ADJUSTABLE MULTI-SPINDLE DRILLING MACHINES, WITH HYDRAULIC FEED (*J. Archdale & Co., Ltd.*)

is supplied with either circular or rectangular head frames. The circular head frame has a maximum of sixteen spindles, and can be used for drilling up to sixteen $\frac{7}{8}$-in. diameter holes; the rectangular head frame is fitted with a maximum of twenty-four spindles for drilling up to twenty-four $\frac{1}{2}$-in. diameter holes. This machine has a separate motor-driven feed unit.

Fig. 28 illustrates a similar but smaller machine suitable for operation by unskilled labour, with twelve spindles for drilling up to twelve $\frac{1}{2}$-in. holes. The 5-h.p. motor also drives the hydraulic feed unit.

Special-purpose High-production Drilling Machines

Interesting special-purpose drilling machines are shown in Figs. 29–32.

A machine for simultaneously drilling the two side faces of a Diesel engine crankcase is shown in Fig. 29. It is a fixed-centre horizontal machine with hydraulic feed. The heads are electrically interconnected and controlled from a single push-button station.

Fig. 30 illustrates a three-way multiple-spindle machine with hydraulic feed.

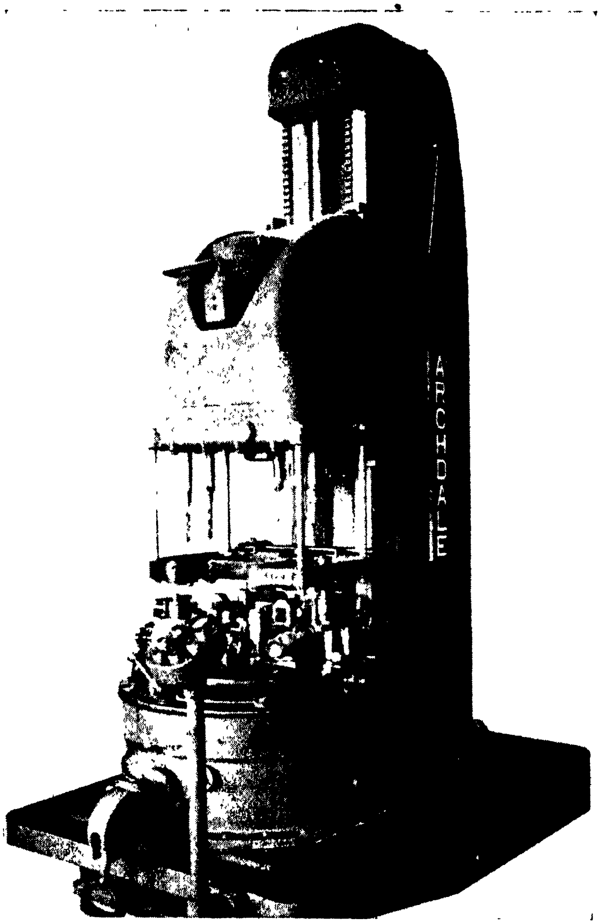


FIG. 29.—FIXED-CENTRE MULTI-SPINDLE DRILLING MACHINE, WITH HYDRAULIC FEED (*J. Archdale & Co., Ltd.*)

The two horizontal and the vertical heads drill simultaneously the rear end and side faces of a tractor engine transmission case.

A drilling machine with six spindles, two for drilling, two for rough taper reaming, and two for finish taper reaming swivel pins, is shown in Fig. 31. This fixed-centre hydraulic-feed machine has a 36-in. diameter hand indexing a four-position circular table, carrying a four-station fixture locating and clamping one pair of components (left and right hand) at each station. The automatic cycle of the machine is: rapid approach to work—feed—reduced feed and "dwell" for finish taper reaming—rapid return to starting position.

Fig. 32 shows a five-way automatic drilling and tapping machine for drilling and tapping gear-pump bodies and plates. Four heads are for drilling, and the fifth is a four-spindle tapping head. The heads are mounted on a fabricated bed around a 36-in. diameter automatic indexing circular table which carries a set of interchangeable fixtures for either bodies or plates. All heads are electrically interconnected and operated from a single push-button station.

Drilling Deep Holes

Fig. 33 shows another special type of drilling machine for drilling deep holes. In these machines the work revolves and the drill is stationary. Fig. 33

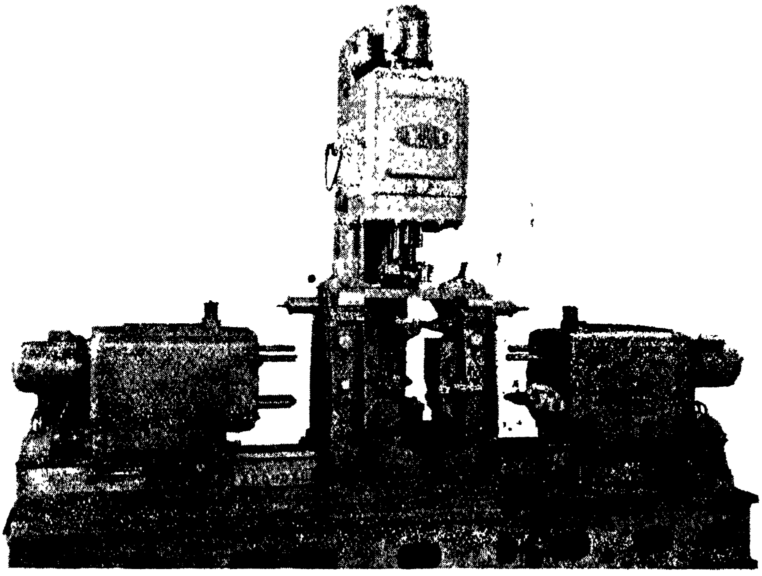


FIG. 30.—THREE-WAY MULTIPLE-SPINDLE DRILLING MACHINE, WITH HYDRAULIC FEED

This is a special-purpose machine which has been designed to drill simultaneously the bolt holes on the rear end and two side faces of an engine transmission casing. The feeds on the three drilling heads are operated by electrically driven hydraulic feed units. (*J. Archdale & Co., Ltd.*)

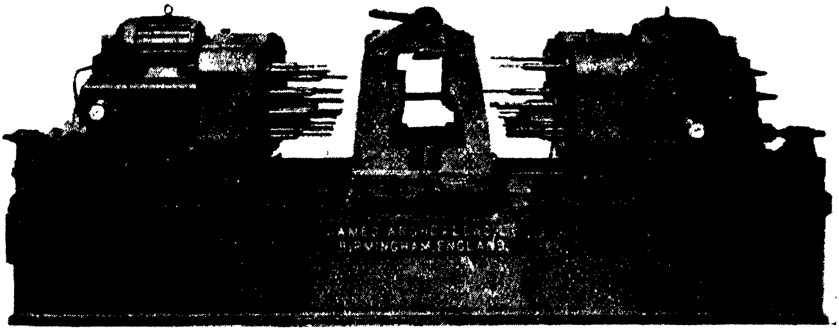


FIG. 31.—DUPLEX HORIZONTAL FIXED-CENTRE MULTIPLE DRILLING MACHINE, WITH HYDRAULIC FEED

This machine has been designed for simultaneously drilling the bolt holes on the two side faces of a Diesel-engine crankcase. (*J. Archdale & Co., Ltd.*)

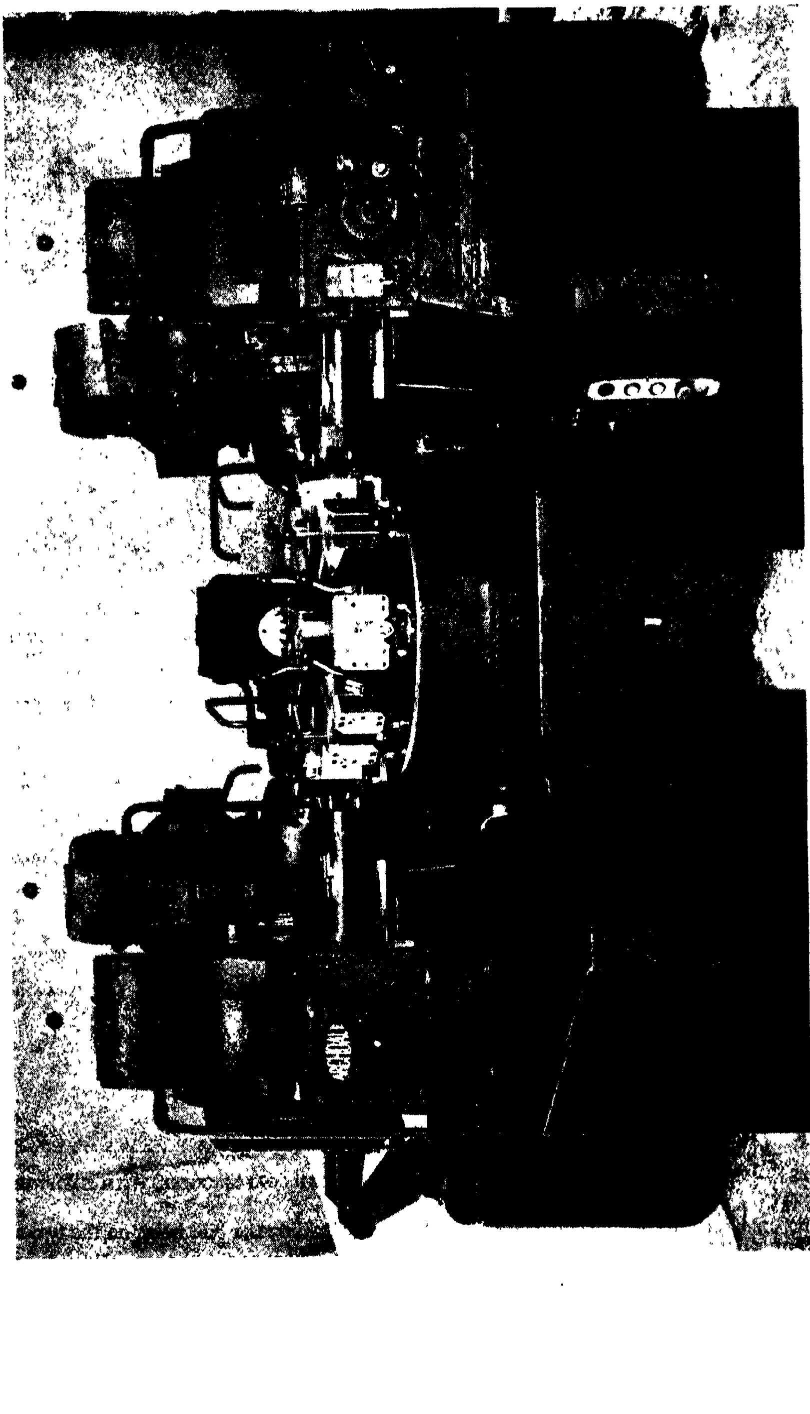


FIG. 32.—FIVE-WAY AUTOMATIC DRILLING AND TAPPING MACHINE (*J. Archdale & Co., Ltd.*)

shows a connecting rod being operated on. The drill will be seen below. The connecting rod is revolved and fed down on to the drill with a reciprocating motion to clear the hole. The machine shown has a maximum capacity of $\frac{7}{16}$-in. diameter with a depth of $13\frac{1}{2}$ in. A 5-h.p. motor is fitted.

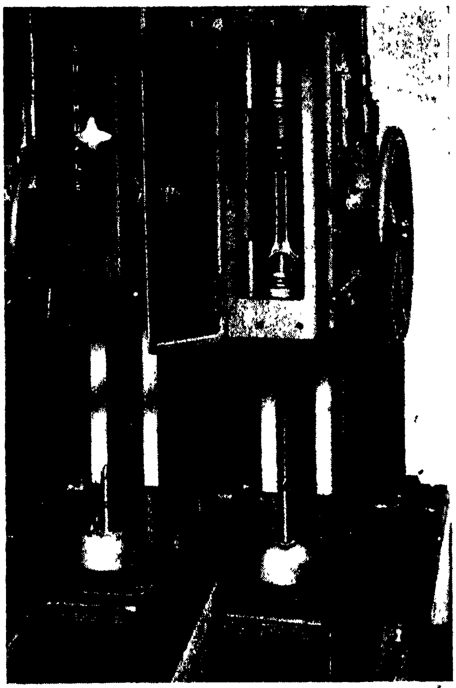


FIG. 33.—CLOSE-UP VIEW OF THE WORKHEAD ON ONE SPINDLE OF REVOLVING WORK-TYPE DRILLING MACHINE

Showing connecting rod and stationary drill. (*J. Archdale & Co., Ltd.*)

Vertical Crankshaft-drilling Machine with Photo-electric Control

Figs. 34–37 show part of a machine designed for drilling and reaming through the centre mains of both four- and six-throw crankshafts for oil and petrol engines, in which use is made of a photo-electric cell to control the various operations involved.

The movements required of the drilling and reaming spindles can be visualised by an examination of the crankshaft. The first movement required is a fast traverse of the drill to the cutting position, then slow feed at drilling speed into the work and, after the drill has traversed about 2 in. into the crankshaft, a fast reversal of the drill spindle is required in order to remove the drill from the crankshaft so that the accumulation of swarf may clear itself from the drill.

Next, a fast downward movement of the drill is required to being the drill back to the position where it last left off cutting and at this point to traverse forward again at feed rate. According to the length of the journal being drilled, so must the number of such reversals be arranged for clearing the drill. When the hole is completed through one journal, a fast traverse is possible through the gap before the succeeding journal is reached.

These traverses at fast rate in both the upward and downward directions, together with forward traverses at drilling feed rate, are continued successively until the operation is completed, when the machine automatically reverses to its starting position and stops.

Without some system of photo-electric control the variations in the traverse required for both the drilling and reaming operations on crankshafts of varying

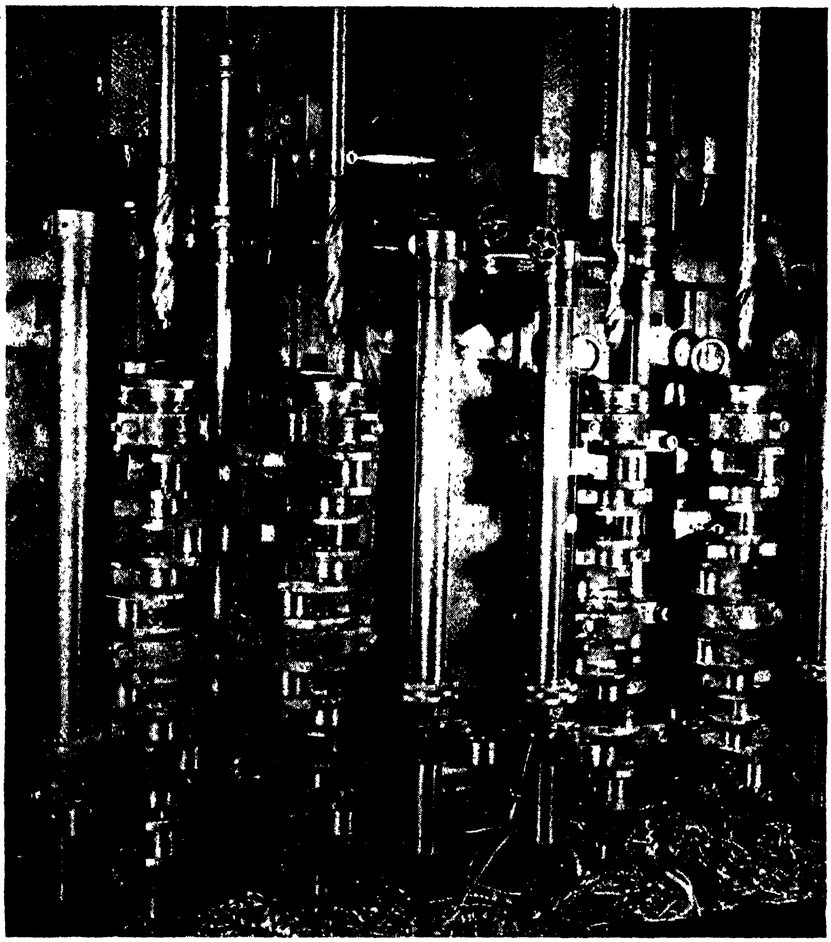


FIG. 34.—VERTICAL CRANKSHAFT-DRILLING MACHINE WITH PHOTO-ELECTRIC AUTOMATIC CONTROL

Front view, showing crankshafts in position ready for drilling. (*A.E.C., Ltd.*)

dimensions would require elaborate and lengthy resetting of mechanical control or cam action.

The Photo-electric Control Unit

The photo-electric control units governing the operations are situated on the outside surfaces of the two columns of the machine. For the transmission of the light ray to the photo-electric cells a disc is used in which slots are cut in two tracks on different diameters. As these discs rotate, a light beam penetrates

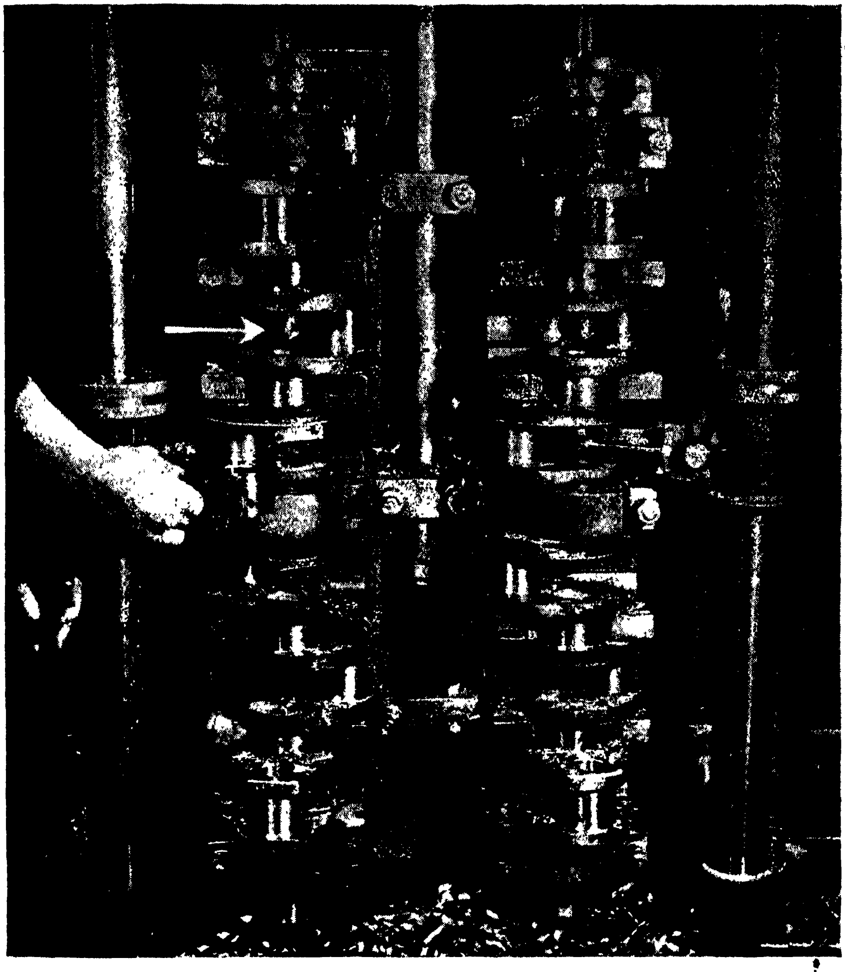


FIG. 35.—VERTICAL CRANKSHAFT-DRILLING MACHINE
Placing the pilots to steady the drills. (*A.E.C., Ltd.*)

the slots which are cut at predetermined intervals in relationship with the sequence of operations required, on either one or both of the sensitive cells, the impulses from which, after being amplified by valves, operate electric contractors for forward and reverse motions of a reversible electric motor which drives the forward and reverse traverses of the heads in which the drills and reamers are mounted.

The discs are geared in unison with the forward feed of the tools, through

FIG. 36.—VIEW OF FEED BOX OF VERTICAL CRANKSHAFT-DRILLING MACHINE (*A.E.C., Ltd.*)

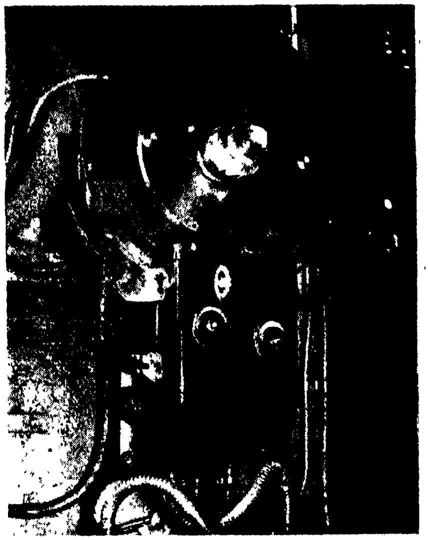


FIG. 37.—THE PHOTO-ELECTRIC UNIT FOR THE AUTOMATIC CONTROL OF A VERTICAL CRANKSHAFT-DRILLING MACHINE (*A.E.C., Ltd.*)

the medium of shafts extended from the feed units, which are housed inside the column of the machine.

Several features of this interesting machine are patented both at home and abroad.

JIG DRILLING

Jigs are used very extensively in drilling, and their use enables very large quantities of work to be produced in the minimum time. For the purpose of considering the use of jigs in drilling, we will take an actual example of an

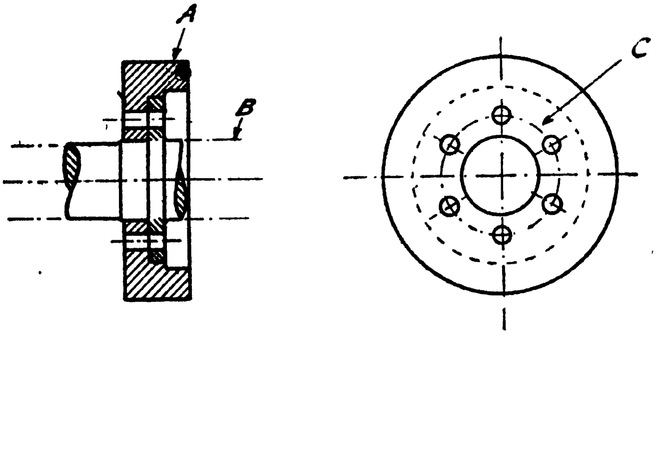
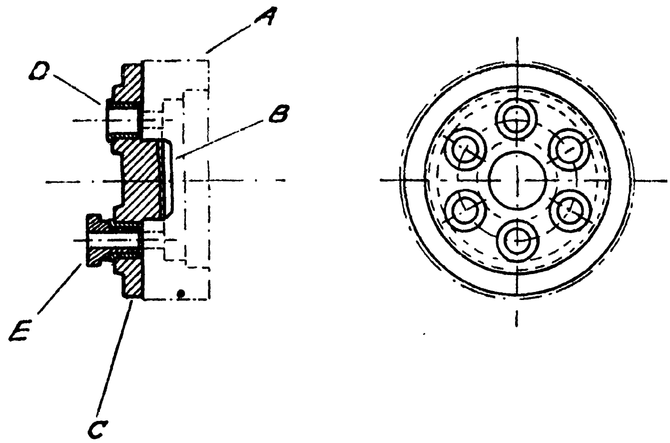


FIG. 38.—A TYPICAL DRILLING JIG

This is for a gear-wheel blank which requires to have six holes drilled in it for the holding bolts. *A*, wheel blank; *B*, flanged shaft; *C*, holes

FIG. 39.—TYPE OF JIG EMPLOYED FOR PRODUCTION OF MEDIUM QUANTITIES OF GEARWHEEL SHOWN IN FIG. 38

A is the wheel to be drilled; *B* is the jig-locating plug; *C*, jig body; *D*, liner bushes; *E*, removable bushes.



engineer's gearwheel which requires to have the holes drilled in it for the holding bolts.

The gearwheel is shown in Fig. 38. *A* is a gear-ring. *B* is a flanged shaft to which *A* is to be held by six bolts through the six holes shown. The bolts are to fit the holes closely and the holes are to be reamed.

The Marking-out Method

Supposing quite small quantities were required, the methods of production would probably correspond to those employed about sixty years ago.

The two pieces *A* and *B* would be turned and fitted together as shown. The piece *A* would then be taken and a circle *C* would be marked upon it with compasses and as nearly concentric with the central hole as possible.

Upon this circle would then be marked by compasses the six holes, spaced as equally as possible. In the centre of each hole in the circle *C* a heavy centre mark would be made to start the drill truly. The drill would then be made to follow as nearly as possible each hole in turn as marked out.

Next, *A* would be put on to shaft *B*, and the six holes drilled in the shaft flange. *A*, of course, would act as a guide for the drilling of the flange in *B*.

The six holes in pieces *A* and *B* would then be reamed while in position as shown.

A Slow and Costly Procedure

Now, this method, while producing good work, would not make the pieces interchangeable,

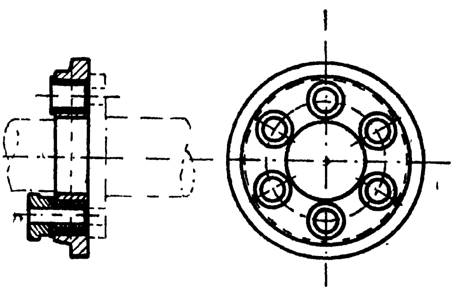


FIG. 40.—JIG FOR DRILLING FLANGED SHAFT FOR MEDIUM PRODUCTION

so that in the event of a breakage it would be necessary to make a new piece and match it with the unbroken part. Moreover, the marking out of each piece would be a slow and costly procedure.

Introduction of Drilling Jig

Let us now take the method that would have been used about thirty years ago, which required the production of medium quantities—say, fifty wheels per week.

Fig. 39 shows the type of jig commonly used for drilling the wheel shown in Fig. 38.

A is the wheel to be drilled.

B is a locating plug which centres the jig truly in the wheel.

C is the jig body.

D is one of the liner bushes driven tightly into the jig body.

E is one of the removable bushes fitting the fixed liner bushes. One bush *E* would be for guiding the drill; another bush would be for guiding the reamer.

Method of drilling the Wheel

The method of drilling the wheel by means of the jig would be this. The locating plug *B* would be put into the centre hole of the wheel and the face of the jig would be brought against the edge of the wheel as shown in Fig. 39. The jig with the wheel underneath would be placed on the drilling machine table.

Then the drill bush *E* would be put into one of the liner bushes and a hole drilled. Each hole in turn would be drilled in this way. After drilling one hole it is necessary to put in a plug which will fit the liner bush and the hole drilled in the wheel.

The remainder of the holes can then be drilled without fear of the jig moving round on the central plug *B*.

Reaming the Holes

After the holes are all drilled, a reamer bush is put into a liner bush, and each hole in turn is reamed, care being taken that a plug is inserted as before, after reaming the first hole. The shaft would be drilled in a similar manner as in Fig. 40.

Mass-production Method

If large quantities of such a wheel were to be drilled to-day, a drilling machine would be arranged as what is called a "single-purpose machine." It would have six spindles, and all six of the holes would be drilled together.

This machine would be arranged as a jig and drilling machine combined; that is, each drill would be accurately guided.

D. J. S.

BORING WITH HORIZONTAL MACHINES

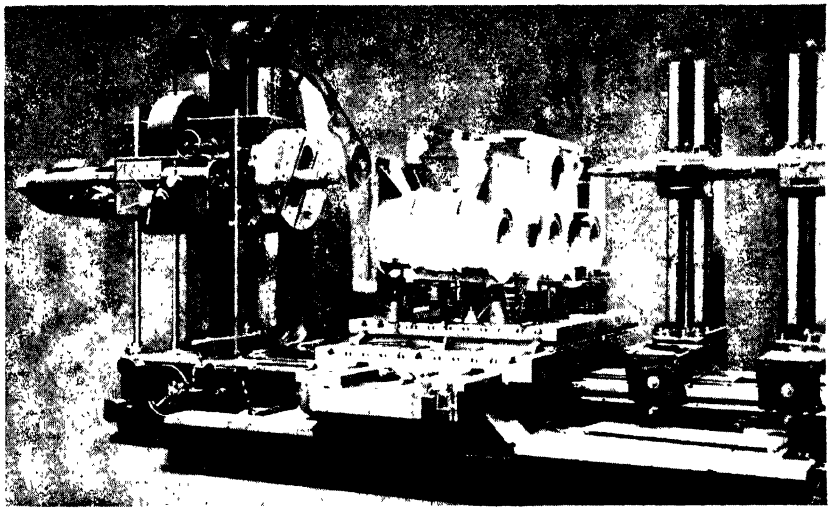


FIG. 1.—HORIZONTAL BORING A MONO-BLOCK CYLINDER CASTING ON A KEARNS NO. 5 WIDE-BED PATENT MACHINE

BEFORE describing the various operations which can be carried out on a horizontal boring machine, it is important to note the general types of machines available.

Types of Machines

First, there is the plain spindle type of machine as shown in Fig. 2, which is particularly suitable for boring, milling, drilling, and tapping operations.

The second type is the non-travelling spindle machine with a built-in automatic facing chuck. This machine is capable of surfacing, boring, milling, and drilling operations, and an outline is given in Fig. 3.

A further type of machine combines the features of the first and second ones (Fig. 4), in that it has a travelling spindle combined with an automatic facing chuck. The work is carried, as in the first two examples, on a revolving table, which is mounted on a compound main table.

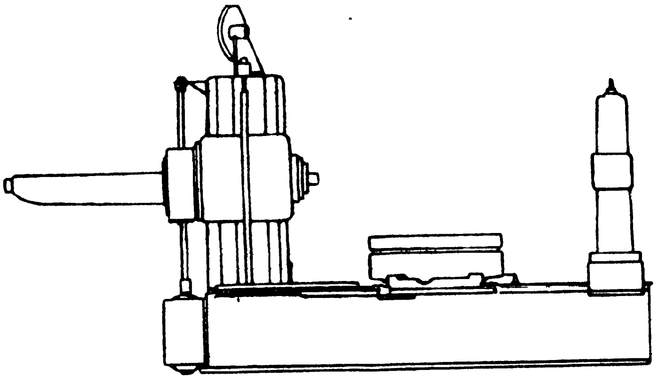


FIG. 2 (*left*).—PLAIN SPINDLE HORIZONTAL BORING MACHINE

This machine is used for boring holes of long length.

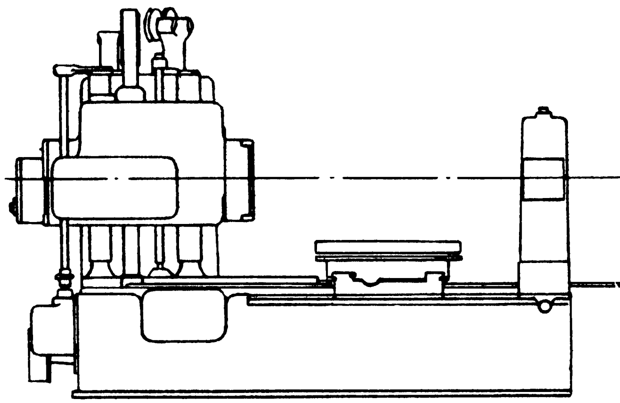


FIG. 3 (*right*)—NON-TRAVELLING SPINDLE MACHINE WITH BUILT-IN AUTOMATIC FACING CHUCK

This machine is recommended where facing operations predominate or for boring holes of short length.

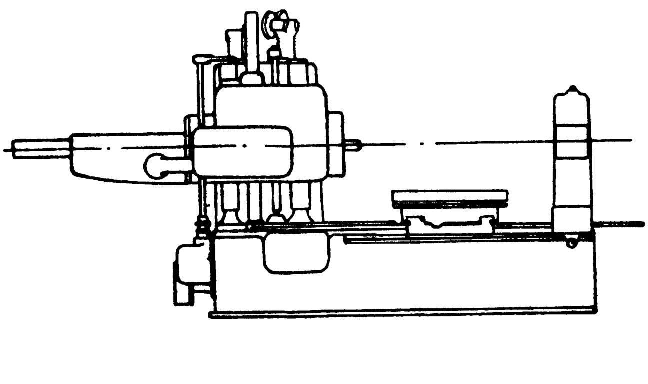


FIG. 4 (*left*).—COMBINED TRAVELLING SPINDLE AND FACING CHUCK MACHINE

This is a combination of the two machines shown in Figs. 2 and 3.

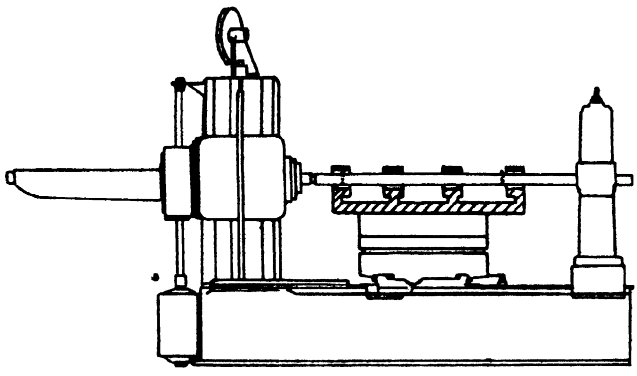


FIG. 5 (*right*).—ILLUSTRATING THE USE OF THE PLAIN SPINDLE MACHINE FOR LARGE BORES

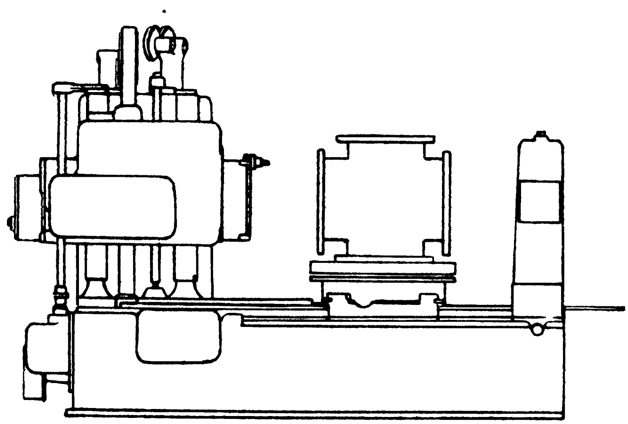


FIG. 6 (*left*).—ILLUSTRATING FACING OPERATIONS ON THE NON-TRAVELLING SPINDLE TYPE OF MACHINE

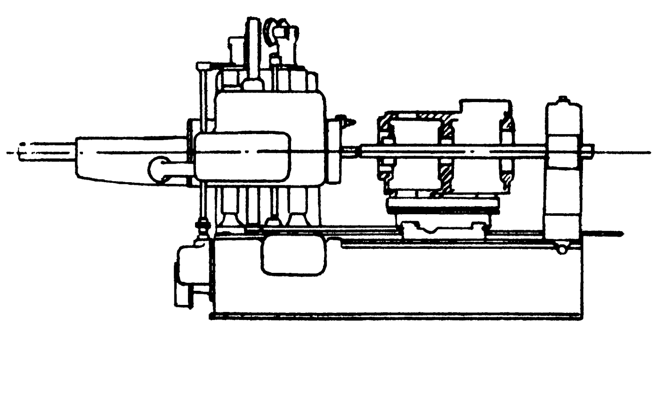


FIG. 7 (*right*). — SHOWING BORING AND FACING OPERATIONS ON THE COMBINED TRAVELLING SPINDLE AND FACING CHUCK MACHINE

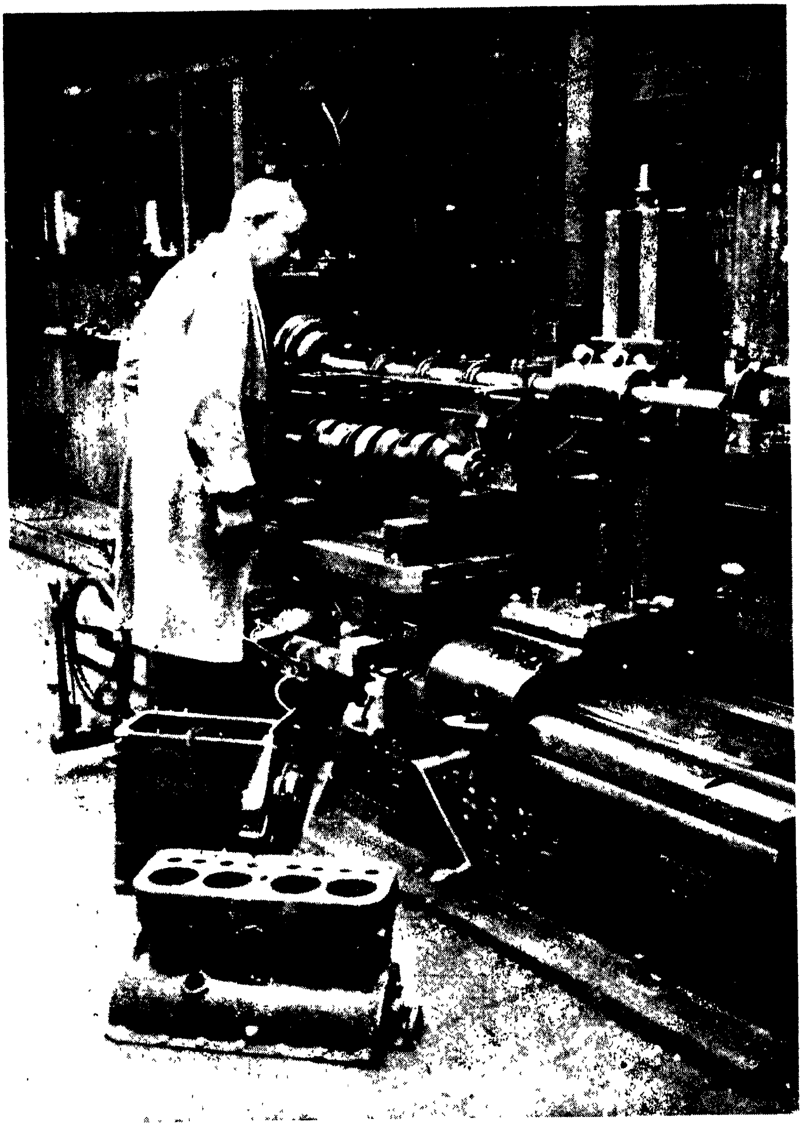


FIG. 8.—BORING SMALL PETROL-ENGINE CRANKCASE ON A PLAIN SPINDLE HORIZONTAL BORING MACHINE

The operation being performed is the line boring of the main bearings.

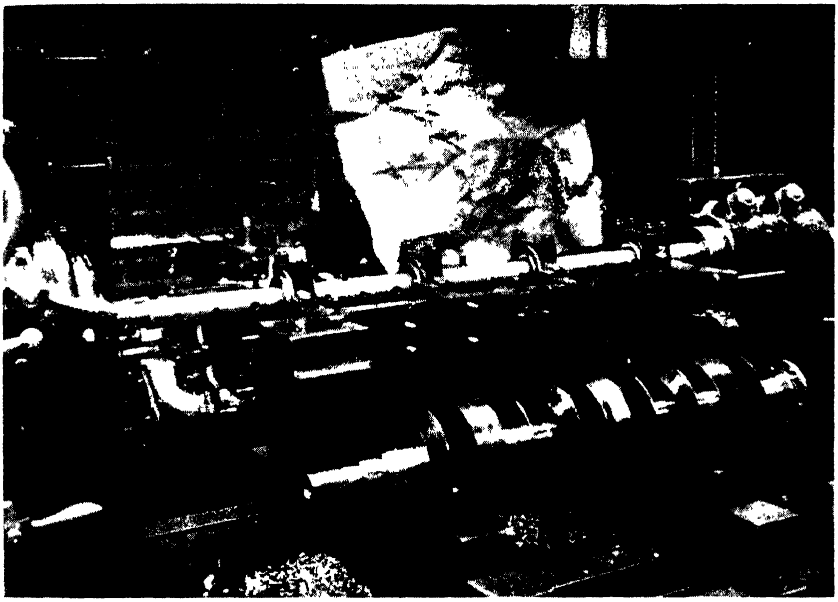


FIG. 9.—CLOSE-UP VIEW OF FIG. 8

Selection of Type

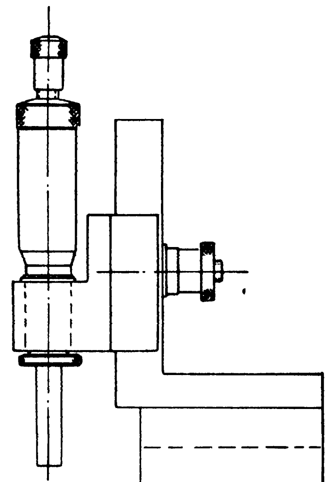
In determining the correct type of machine to use for different classes of boring and facing work, no hard-and-fast rule can be applied, but the following examples, shown in Figs. 5, 6, and 7, can be used as guide.

Fig. 5 shows a component where the holes to be bored are long and the facings of such dimensions that they can be dealt with by cutters mounted in the boring bar. For this class of work the plain spindle type of machine should be used.

For work in which facing operations predominate, or the holes to be bored are very short in length, the non-travelling spindle type of machine is recommended, as shown in Fig. 6.

When the component has bores and facings to be dealt with, as illustrated in Fig. 7, the operations can best be performed on the third type of machine. The boring would be done by the travelling spindle, a method which gives maximum support to the boring bar. At the same time, the distance between the facing chuck and boring stay can be reduced to a minimum, because the traverse of the boring bar is obtained from the travelling spindle, the work remaining stationary.

The facing is performed by the automatic facing chuck, the depth of cut being obtained by slightly moving the work table. This class of work is ideally suited for this type of machine.



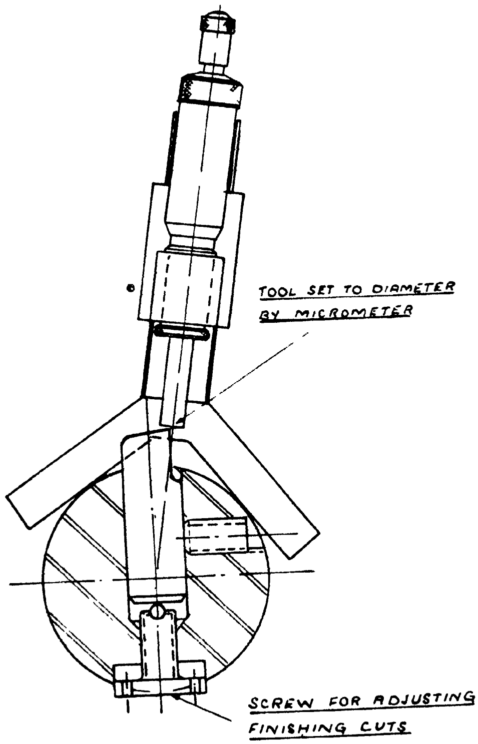


FIG. 10.—MICROMETER GAUGE FOR SETTING TOOLS IN BORING BARS

In deciding on the type of horizontal boring machine to be used, the following broad outline should be followed:

(*a*) The diameter of the travelling spindle should be large enough to deal with the holes to be bored, bearing in mind the material to be cut and the amount to be removed.

(*b*) A table large enough to give full support to the work, and therefore reduce inaccuracies.

(*c*) Use a machine with an automatic facing chuck for all facing operations, unless the diameter can be machined by cutters mounted in the boring bar.

The following examples illustrate the practical use of the types of boring machines previously discussed.

Plain Spindle Machine

Figs. 8 and 9 show a plain spindle machine dealing with the boring of a small petrol-engine crankcase. The operation being performed is the line boring of the main bearings. The camshaft bores would be dealt with in a similar manner.

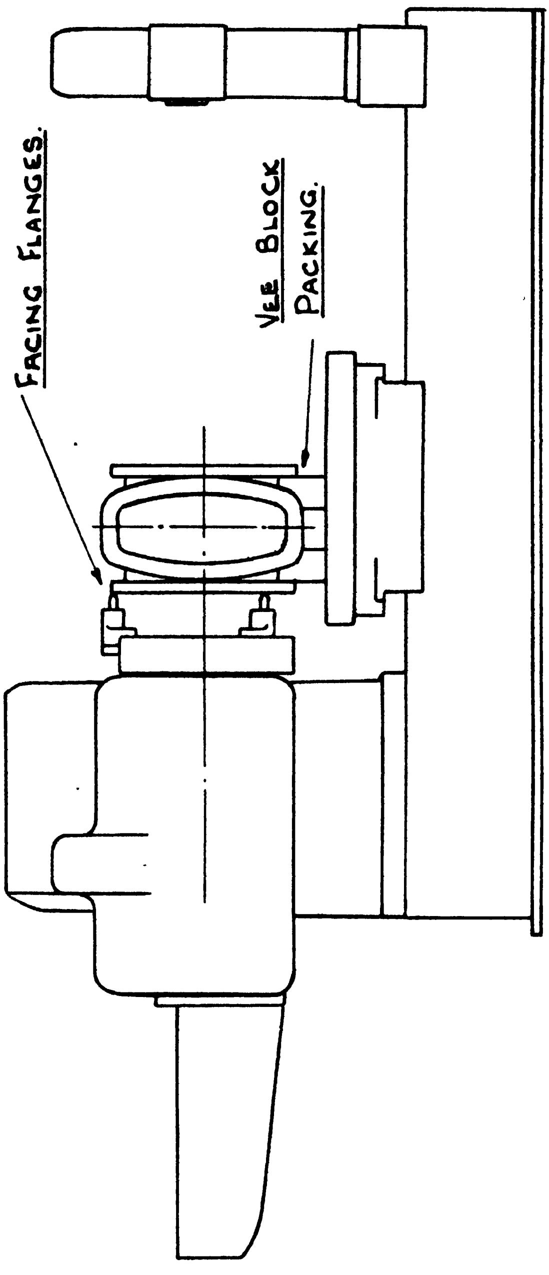


FIG. 11.—MACHINING A 24-IN. WATER-SLUICE VALVE BODY ON A NON-TRAVELLING SPINDLE MACHINE

One of the tungsten-carbide-tipped facing tools is set on the automatic facing slide to the maximum diameter of the flange, and the second tool is set on the opposite side of the facing slide to the inside diameter of the flange. By this method the time to traverse the width of the flanges will be reduced to a half, as each tool will only have to travel half the flange width.

When carrying out the finishing operation, a single tool is used to obtain the maximum degree of accuracy on the face.

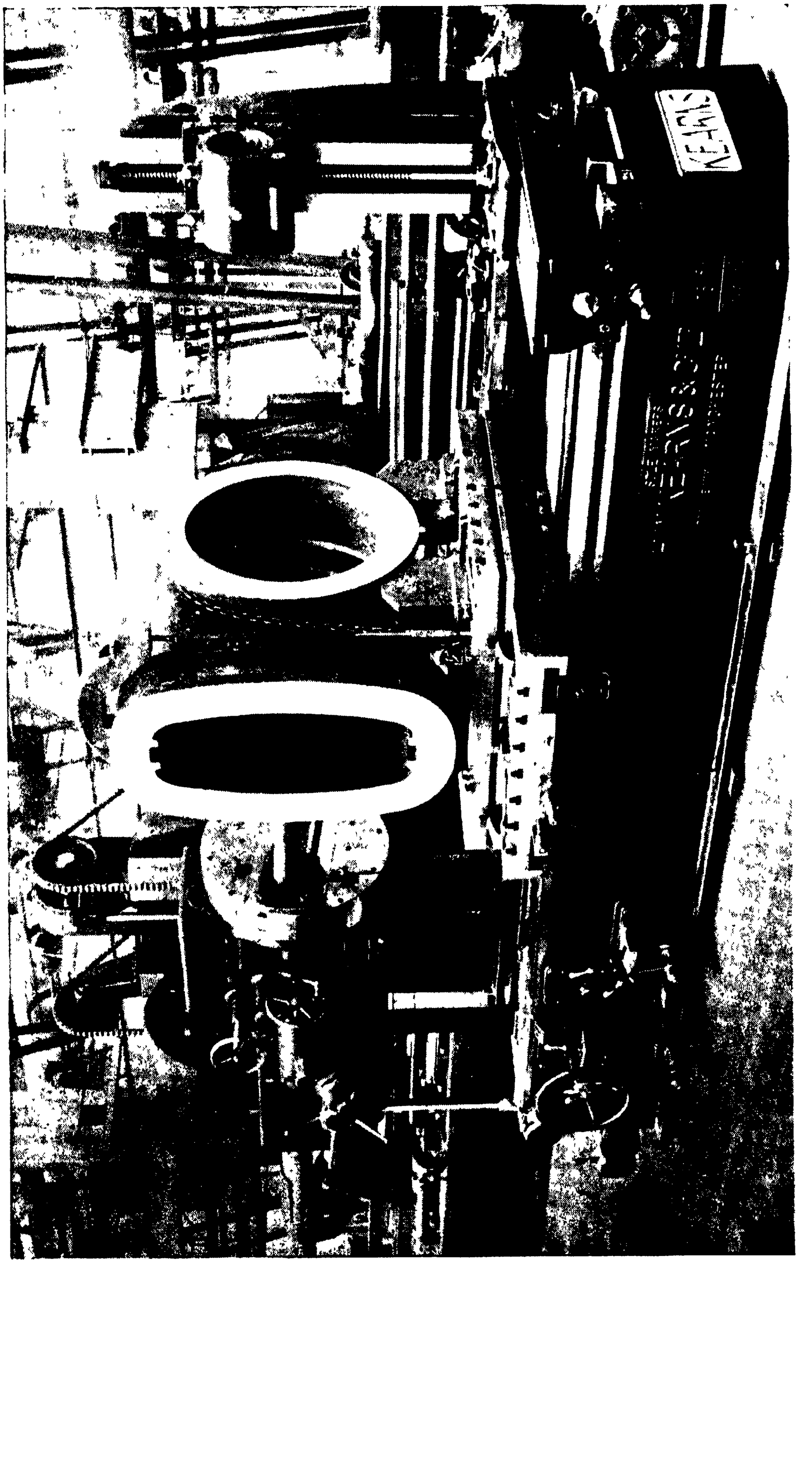


Fig. 12.—Boring the wedge-ring seatings on a 24-in. water-sluice valve body in a non-travelling spindle machine

With the crankcase mounted on the work table, the spindle slide and boring-stay bearing are set to the correct height. At the same time, the distance between the boring-stay bearing and the spindle slide is reduced to a minimum in order to ensure a rigid support for the bar. This reduced overhang of the boring bar helps to reduce to a minimum the deflection and, consequently, increases the accuracy of the boring operation.

The illustrations also show that a maximum diameter of bar is being used; this is of the greatest importance if high production and a fine finish in the bore are to be obtained.

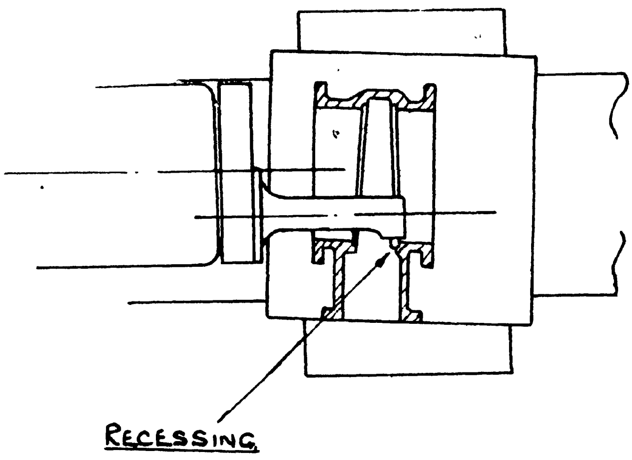


FIG. 13.—ILLUSTRATING THE USE OF A SNOUT BAR WHEN CUTTING RECESSES

For setting the tools in the boring bar to the correct diameter, the holes for the tools are arranged with a micrometer adjustment, details of which are shown in Fig. 10. From this it will be seen that the micrometer adjusting screw is fitted with a hardened-steel ball at the point of contact with the bottom of the cutting tool; this ensures that the tool will be lifted an amount equal to the movement of the screw. A bar micrometer is used for measuring the diameter to which the tools are set; this is also shown in Fig. 10. For this operation, the work table remains stationary and the main spindle is traversed to give the necessary axial feeding motion to the boring bar.

On this same type of machine, the cylinder lines can be bored, also the seating for the crankshaft caps and cylinder head face machined, by mounting milling cutters on the spindle sleeve.

Non-travelling Spindle Machine

This type of machine, with its built-in automatic facing chuck and non-travelling spindle, is particularly suitable for the machining of various designs of valves. Fig. 11 illustrates the method adopted for dealing with a 24-in.

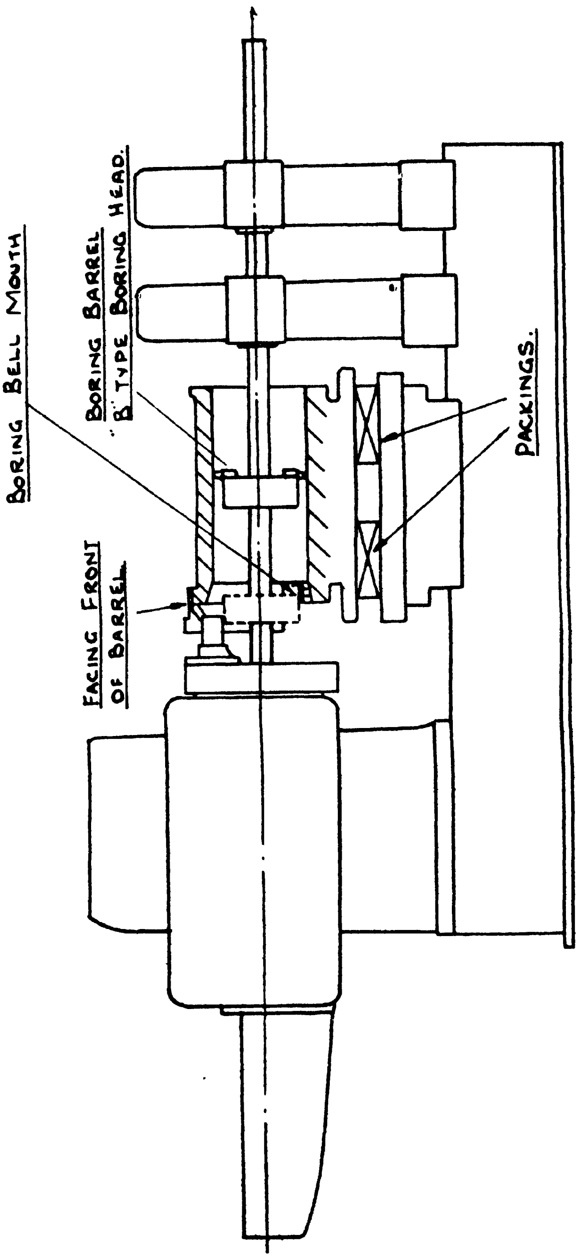


FIG. 14.—LAYOUT FOR MACHINING A SINGLE-CYLINDER LOCOMOTIVE CASTING IN A COMBINED TRAVELLING SPINDLE AND FACING CHUCK MACHINE

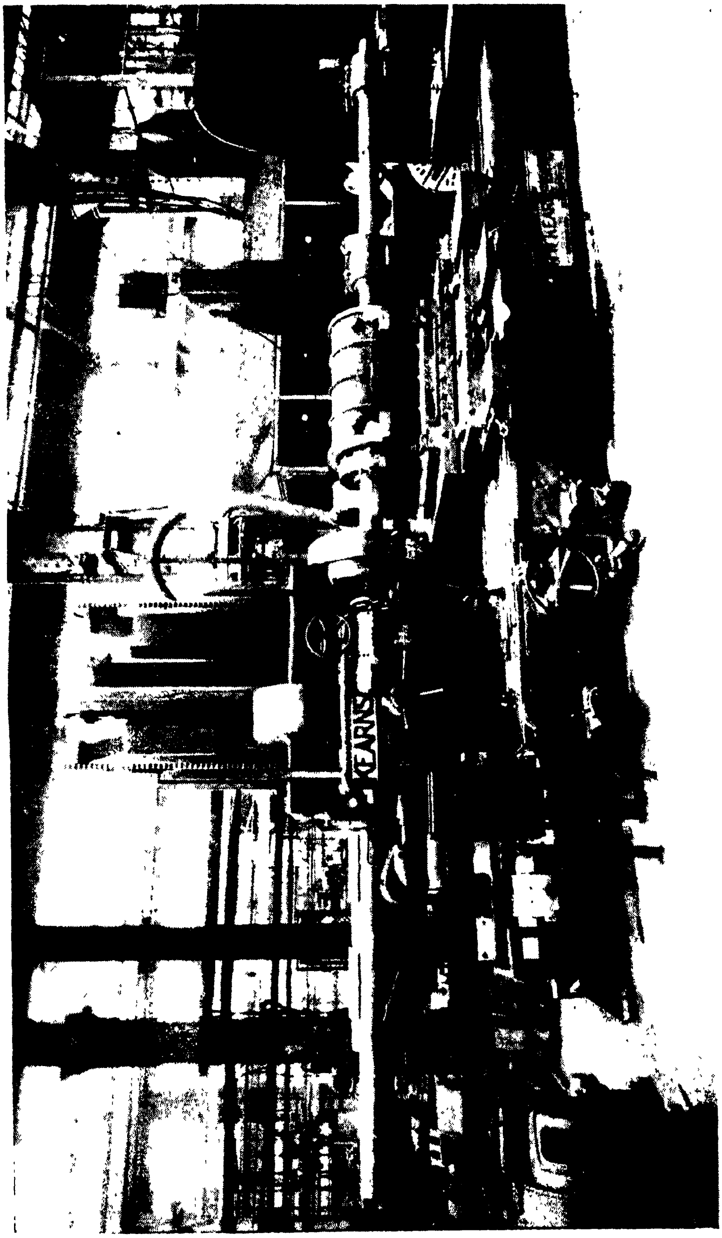


FIG. 15.—HORIZONTAL BORING MAIN-CYLINDER LINE OF LOCOMOTIVE CYLINDER CASTING IN A COMBINED TRAVELLING SPINDLE AND FACING CHUCK MACHINE

water-sluice valve body, while Fig. 12 shows a machine of this type boring the seatings for the wedge rings.

From Fig. 12 it will be seen that the valve is set in V-blocks mounted on the revolving table of the machine. Clamping of the valve body is by means of two chains and an additional V-clamp on the dome section. The facing operation is first carried out by setting two tungsten-carbide-tipped facing tools on the automatic facing slide, as shown in Fig. 11. One is set to the maximum diameter of the flange and the second, on the opposite side of the facing slide, to the inside diameter of the flange. By this method the time to traverse the width of the flanges will be reduced to a half, as each tool will only have to travel half the flange width.

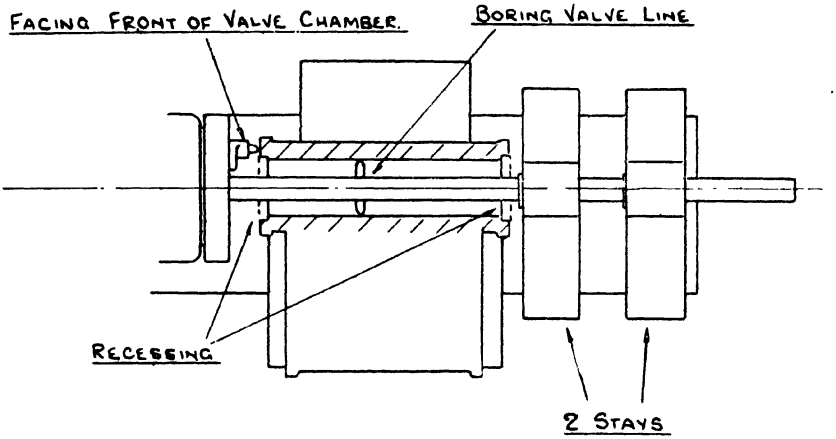


FIG. 16.—BORING PISTON-VALVE LINE

When carrying out the finishing operation, a single tool is used to obtain the maximum degree of accuracy on the face. The revolving table clamps are released and the table rotated to deal with each face on the valve body.

The boring, recessing, and screwing operations are dealt with by mounting a snout bar on the facing slide, as shown in detail in Fig. 13.

Combined Travelling Spindle and Facing Chuck Machine

This extremely universal type of machine is capable of dealing with a very wide range of operations. Fig. 14 shows a layout for machining a single-cylinder locomotive casting, while Fig. 15 shows a horizontal boring machine boring the main cylinder line on this type of casting.

A sequence of operations for this class of work would be first to set the casting on packings so that the flange is clear of the table. With a facing tool mounted on the facing slide, both ends of the cylinder barrel and piston line are dealt with. Next the barrel is bored by means of a boring head mounted on a

maximum-diameter boring bar. During this operation the work remains stationary and the feed to the boring bar is produced by the axial movement of the travelling spindle. For a cylinder bore of 23 in. and a length of 40 in., a 5-in. diameter boring bar would be used, with tungsten-carbide-tipped tools. The cutting speed is 140 ft. per minute and the feed per revolution $\frac{1}{44}$ in. If a greater cutting speed is attempted, the accuracy of the bores will be affected, due to the wear on the tool.

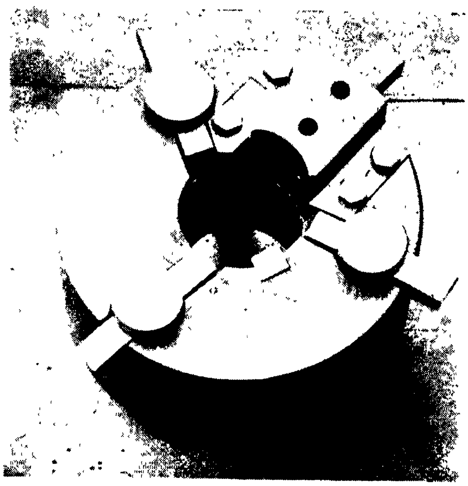


FIG. 17.—BORING TOOL HEAD FOR LARGE BORES

Showing three roughing tools and a finishing tool which is mounted in a sliding toolbox.

When boring the piston valve line, the tools are double-ended and mounted direct into the boring bar, as shown in Fig. 16. In order to obtain a first-class finish in the bores and at the same time to reduce the deflection of the bar, two boring stays must be employed for this operation.

The use of two boring stays also gives full support to the free end of the boring bar, which would otherwise have a detrimental effect on the finish obtained.

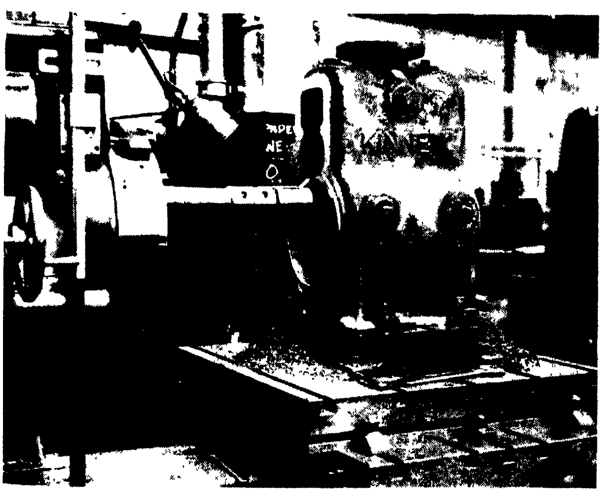


FIG. 18.—SNOUT BORING

Factors governing Successful Boring Operations

In all boring operations it is essential that the maximum diameter of boring bar should always be used. Secondly, the minimum length of unsupported bar will be employed if the work is kept stationary and the axial feed obtained from a travelling spindle. Also, all boring tools should be mounted

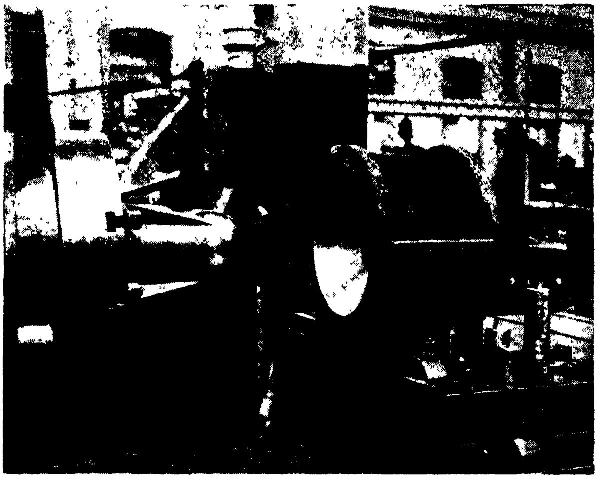


FIG. 19. — SPHERICAL BORING ATTACHMENT

The boring tool is mounted in a holder fixed into a half-head. This example shows a radius of 6 in. being machined.

with a minimum of overhang, and this should not generally exceed half the diameter of the bar. For larger bores, the tools should be mounted in some form of boring head, and Fig. 17 shows an example of this type with three roughing tools and a finishing tool which is mounted in a sliding toolbox. This finishing tool can be adjusted by means of a gearing arrangement to advance in increments of 0·001 in. This adjustment is carried out by hand from the back of the boring head.

Where long bores are encountered, it is absolutely necessary to employ two boring-stay bearings in order to give rigid support to the bar.

When snout boring operations are to be carried out the bar should be mounted in a base of sufficient length to give maximum support to the snout bar. This base usually allows the snout bar to be telescoped into the bore, in order to reduce the overhang where possible. Fig. 18 illustrates a tool of this type in operation.

Spherical Boring

The boring operations so far described have dealt with normal parallel bores, but when necessary spherical boring can be carried out on the combined travelling spindle and facing chuck machine. Fig. 19 shows a spherical boring attachment machining a radius of 6 in. In this case, the boring tool is mounted in a holder fixed into a half-head. This head is pulled round by means of the travelling spindle, to which the range of axial feeds apply, while the rotary motion of the attachment is obtained from the facing chuck on to which the base is bolted. Again, the object is to reduce to a minimum the overhang of the cutting tool and if a greater radius is required, either a new half-head or increased-length tool holder should be fitted.

We are indebted to Messrs. H. W. Kearns & Co., Ltd., for supplying the information and the illustrations to the above article.

MILLING PRACTICE

MILLING is the most versatile of the metal-cutting processes. It combines speed with ability to evolve any shapes, and to repeat them accurately. Hence, many differing types of milling machines have been developed to cut flat surfaces, external and internal, all sorts of grooves, slots, curves, teeth, cams, threads. Alternative methods are possible in many sorts of milling: a contour may be produced with a cutter of similar form; or feed or control can be given to enable a plain mill to generate the outline. Gang operation is very extensively practised, with several distinct mills on an arbor, or several spindles running. Both time saving and uniformity are thereby ensured. Recent practice has speeded up production by the use of high-power mills, made of fast-cutting alloy.

Milling Cutters

The early mills had a large number of teeth to the circle, but in the latest types there are often no more than six, giving a strong tooth section, and ample space between for chips. The problem of preserving the shape of a mill when it has to cut a profile is solved in what are termed form mills. Instead of sloping back straight from the edge, each "land" is a continuation of the shape.

Therefore, by sharpening on the front face as often as necessary, the profile does not alter, but the teeth become thinner. The grinding must be strictly radial, otherwise the profile will be distorted. The exception occurs with the newer raked cutters, ground with top rake for better cutting and the angle specified must be preserved.

Spiral Mills

All but the narrowest mills generally have the teeth at an angle, thus giving a shearing cut, and removing metal with less effort and smoother finish. A very quick spiral is favoured for fast cutting.

When two or more cutters are fastened on an arbor for gang operation, right- and left-hand inclination is selected, to balance end thrusts. Narrow grooving cutters are made with alternate right-hand and left-hand teeth for a similar reason.

Inserted-tooth Cutters

It is not economical to make certain kinds of cutters, and large ones, out of the solid piece of tool steel or alloy. Cost is excessive, tooth breakage causes difficulty of salvage, and sharpening reduces area for chip escape between teeth.

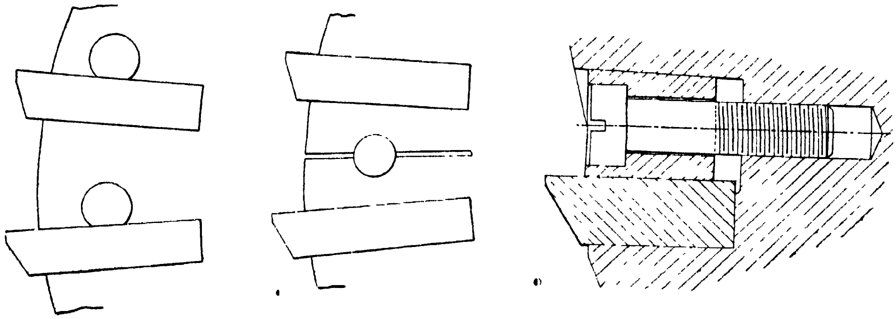


FIG. 1.—SOME METHODS OF HOLDING INSERTED TEETH IN MILLS

Comprising the use of wedge pins, taper pins in splits, and wedge locked by screw. The hole in the wedge is tapped to take an extractor, for removing wedge when the screw has been withdrawn.

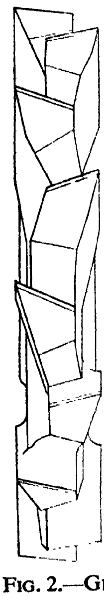
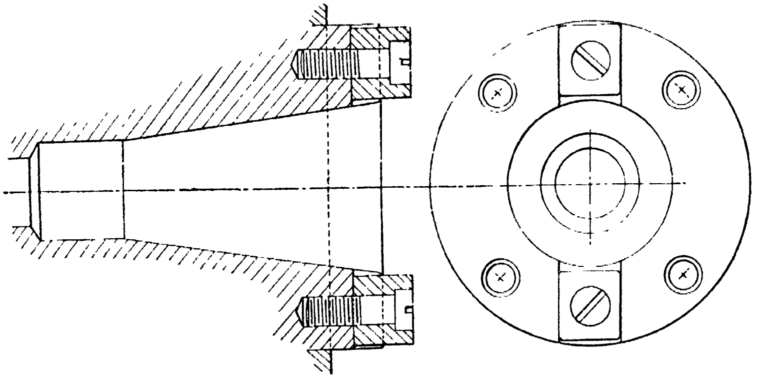
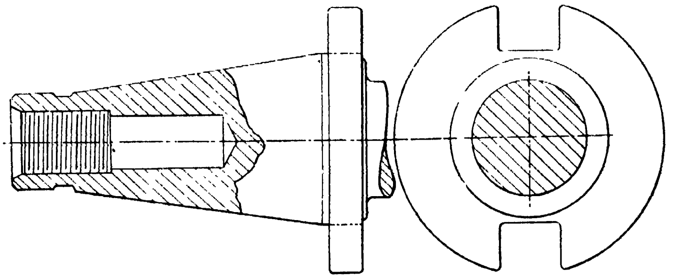


FIG. 2.—GROOVING AND SLOTTING MILL

The spiral teeth are alternate R.H. and L.H., thus avoiding chatter and leaving a good finish.





FIGS. 3 AND 4.—INTERNATIONAL STANDARDISING SPINDLE NOSE, WITH STEEP NON-STICKING TAPER

Large face mills are centred on the outside diameter, fastened by four screws and driven by the keys fitting slots. The end of a cutter-arbor (lower view) is drawn in by a bolt passing through the spindle.

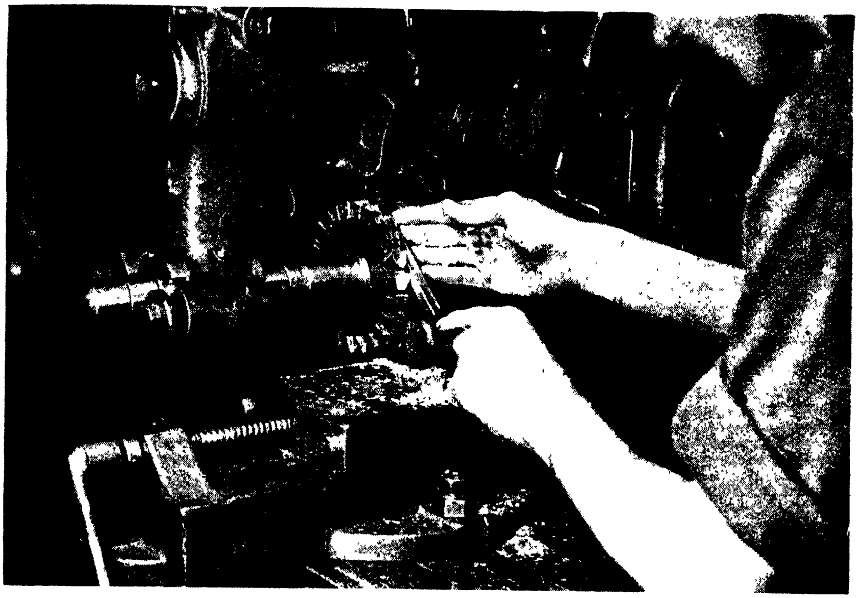


FIG. 5.—MILLING OPERATIONS (1)
Setting the job in vice. (*Tecalemit, Ltd.*)

Varied designs are constructed, with body of non-cutting class of steel, and straight or helical teeth held in either by sweating, clamping with screws or wedges, and often having an end adjustment or lock by screw or rack, which prevents slip.

Holding Cutters

Accurate running is imperative with cutters, so that every tooth takes an equal share of duty. The mills must be finished and ground true, holes in spindles the same, and all surfaces kept free from ill-usage and burrs. Taper fitting of shanks and arbors into spindles ensures concentricity. An international standard taper is now employed to cope with the heavy pressures, which cause tapers of insufficient slope to stick hard, the taper being non-locking. Two keys on the face drive an arbor by slots in its collar, while the body of a face mill fits on the spindle nose, and is attached by four screws.

Arbors

Mills fit on these generally by parallel hole, are driven by keys, and held endwise by nut, with suitable collars or washers to effect spacing as required. For precision adjustment of gang cutters, and to compensate for changes wrought by sharpening, sets of collars of graduated thicknesses in thousandths

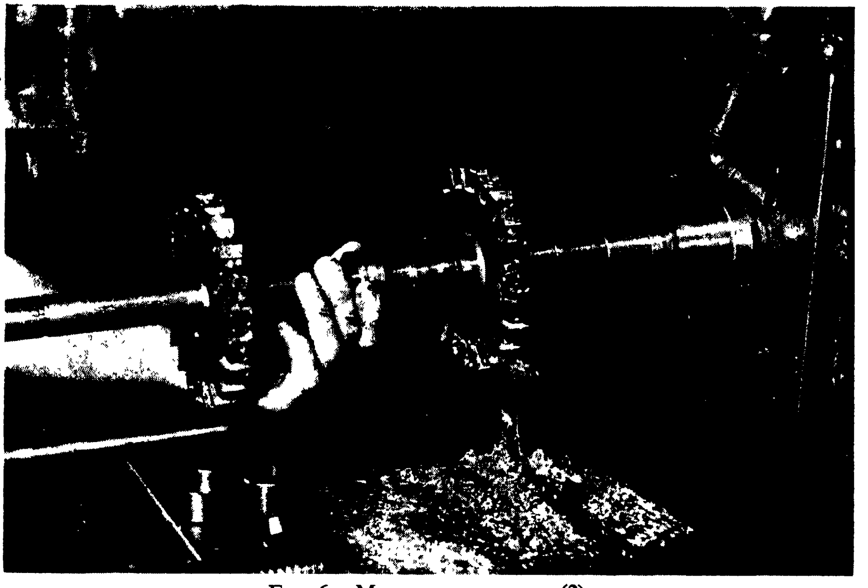


FIG. 6.—MILLING OPERATIONS (2)
Putting packing between cutters for size of job. (*Tecalemit, Ltd.*)

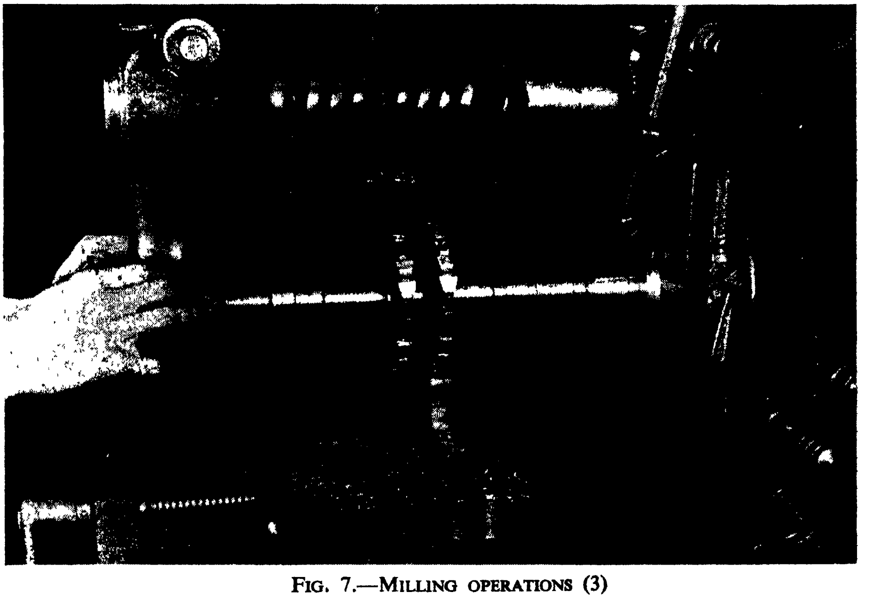


FIG. 7.—MILLING OPERATIONS (3)
Connecting steady arm to support arbor. (*Tecalemit, Ltd.*)

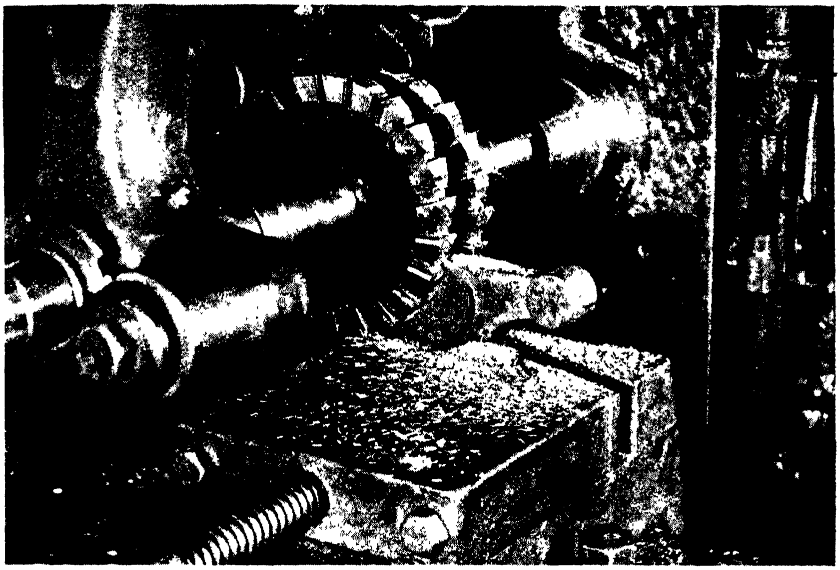


FIG. 8.—MILLING OPERATIONS (4)
Cutting with side and face cutters. (*Tecalemit, Ltd.*)

of an inch are sold, as well as micrometer screw collars made in two parts to spread or contract by a known amount.

Machines

There are more variations in the types of these than in any other class of tool. Spindles lie horizontally, vertically, inverted, inclined, opposed to each other, side by side, superimposed, and may be stationary or travelling. Tables feed linearly or circularly, while special control may result in milling a profile combining straight and curved outlines. The greatest advance in table manipulation is concerned with quick supply of workpieces. A table is long enough to give a loading area while the remaining portion is feeding under the cutters, or the table swivels on a central pivot, permitting a loaded end to be slewed into place for the tooling, whilst the machined work is removed from the other end.

Circular Tables

Work supply with these is possible during the slow rotation, a number of clamps or fixtures being ranged in a circle. Station milling is also performed on a circular table, but the latter feeds in a straight line to and from the cutters, the rotative motion being only utilised intermittently to bring a fresh piece opposite the mills.

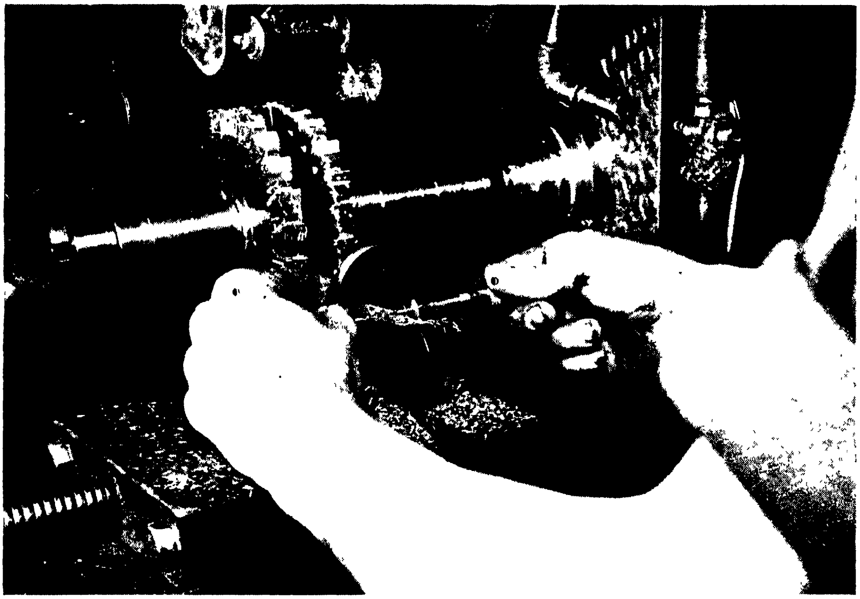


FIG. 9.—MILLING OPERATIONS (5)
Measuring job by micrometer. (*Tecalemit, Ltd.*)

Plain and Universal Millers

These are the most generally useful machines for objects within their capacity. The universals differ in possessing a swivel table for angular settings necessary for many purposes. The machines have undergone extensive changes during recent years in the way of more massive construction, all geared drives and feeds instead of belt changes, and heavy bracings to tie the knee to an overarm projecting from the top of the frame. The construction, however, may be better understood from the light machine shown in Fig. 10, reference letters being: *A* and *N*, longitudinal traverse handles; *B*, surface gauge for work setting; *C*, arbor; *D*, overarm; *E*, lever for engaging back gears; *F*, main driving belt; *G*, overarm locking levers (broken); *H*, driving pulley to automatic traverse; *I*, main-drive cone pulley; *J*, side and face cutter; *K*, cone pulley for automatic traverse; *L*, flexible joint; *M*, telescopic sleeve; *O*, cone pulley on machine countershaft; *P*, drop worm; *Q*, knee-raising screw; *R*, knee; *S*, drop-worm control; *T*, trip and dead-stop lever; *U*, parallels under work; *V*, cross traverse handle; *W*, knee-raising handle; *X*, machine vice; *Y*, the table; *Z*, slot for auto trip and deadstop dogs; Σ, the table-locking screw.

"Manufacturing" Millers

The demand for fast cutting with more than one spindle in operation has led to developments from the plain machines, built very strongly, and with

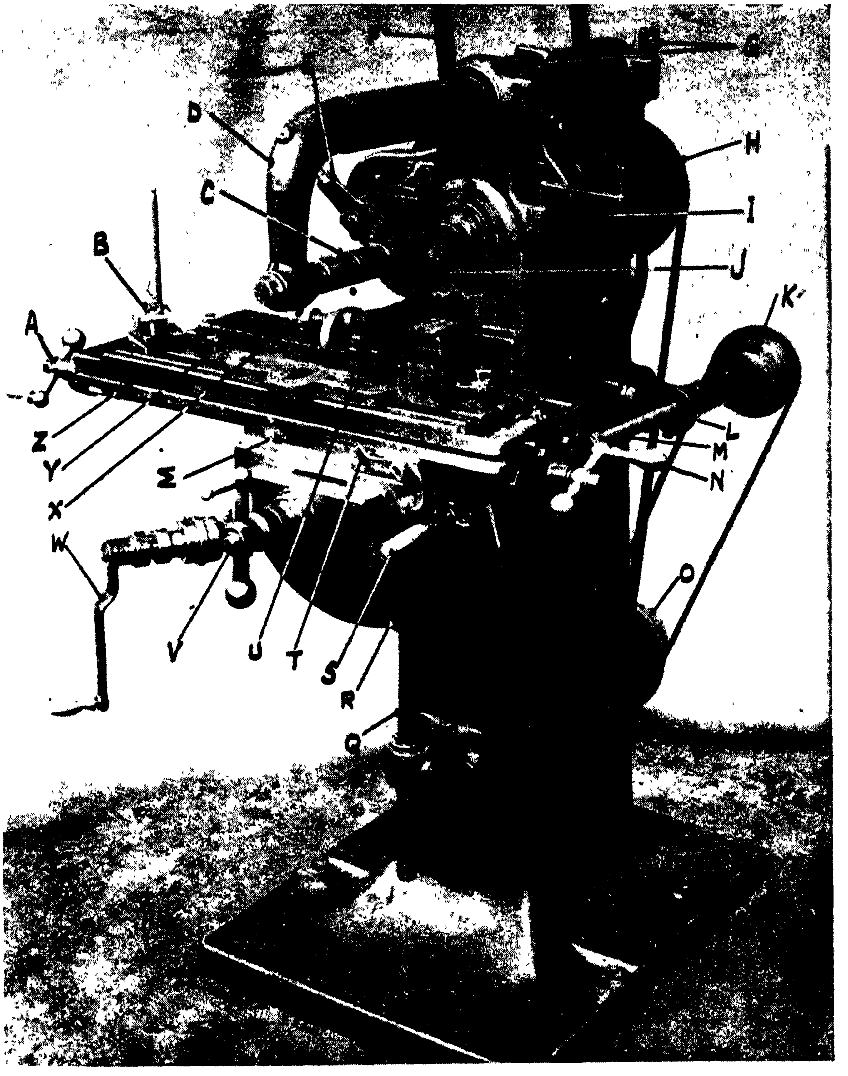


FIG. 10.—SMALL MILLING MACHINE, FROM WHICH THE NAMES OF THE PARTS MAY BE STUDIED

A and *N*, longitudinal traverse handles; *B*, surface gauge; *C*, arbor; *D*, overarm; *E*, lever for engaging back gears; *F*, main driving belt; *G*, overarm locking levers; *H*, driving pulley to auto traverse; *I*, main-drive cone pulley; *J*, side and face cutter; *K*, cone pulley for auto traverse; *L*, flexible joint; *M*, telescopic sleeve; *O*, cone pulley on machine countershaft; *P*, drop worm; *Q*, knee-raising screw; *R*, knee; *S*, drop-worm control; *T*, trip and dead-stop lever; *U*, parallels under work; *V*, cross traverse handle; *W*, knee-raising handle; *X*, machine vice; *Y*, table; *Z*, slot for automatic trip and dead-stop dogs; Σ, table-locking screw.

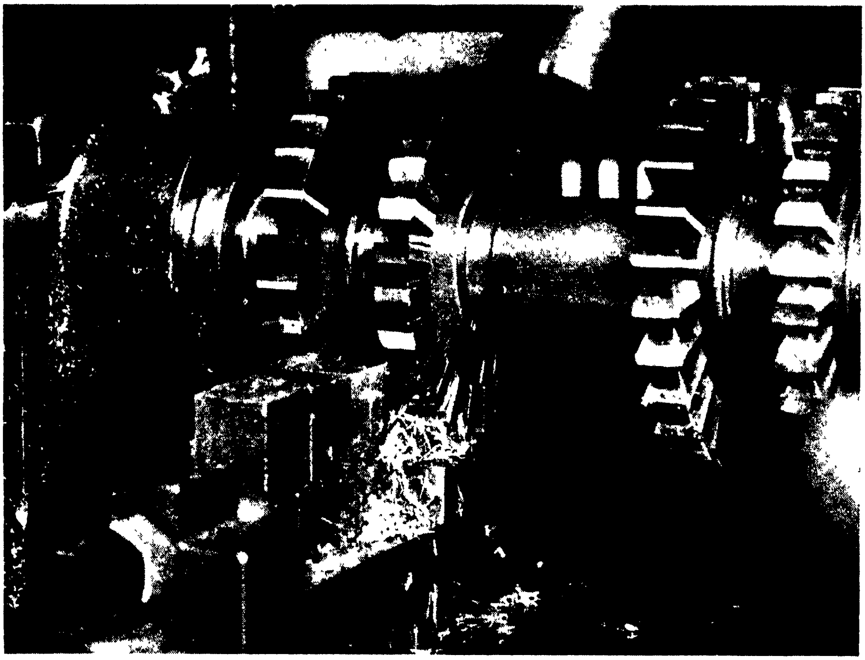


FIG. 11.—FIXTURE AT END OF BROWN & SHARPE AUTOMATIC MILLER TABLE

A similar fixture at the other end comes in line with the second pair of mills seen on the right, the spindle reversing automatically for their use. The picture shows six components clamped in the fixture at one time, and while one fixture load is being milled the other is being loaded. (*Buck & Hickman, Ltd.*)

capacity to fit multi-spindle heads or attachments for horizontal, vertical, or inclined spindles. The table controls are arranged for saving every moment, by giving quick power approach, change to feed, acceleration at gaps, and finally quick return for unloading. The swivelling or indexing table already mentioned may be fitted to avoid delays caused in loading. The Brown & Sharpe automatic machines possess the special feature of auto-spindle reverse, so that by mounting two sets of cutters on the spindle, to suit the lateral position of work pieces clamped at each end of the table, the latter will feed to and fro automatically, and the spindle reverse suitable for each batch of work. Fig. 11 has the pairs of mills in view. The attendant is kept busy stripping and reloading the vice or fixture at the end, which has just come from the cutting position.

Plano-millers

Long or large parts, and gangs, are dealt with on machines having a primary resemblance to planing machines—long bed, sliding table, uprights, and cross-rail. The last-named part has saddles with one or more horizontal, vertical, or

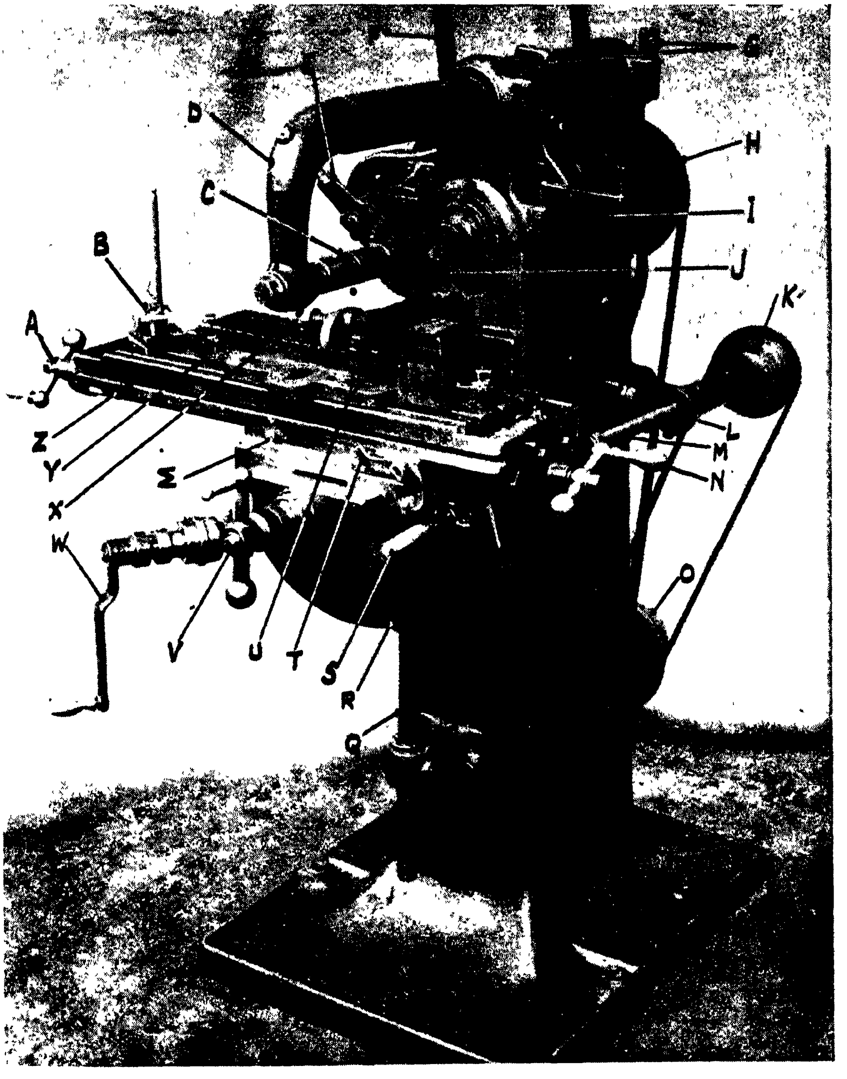


FIG. 10.—SMALL MILLING MACHINE, FROM WHICH THE NAMES OF THE PARTS MAY BE STUDIED

A and *N*, longitudinal traverse handles; *B*, surface gauge; *C*, arbor; *D*, overarm; *E*, lever for engaging back gears; *F*, main driving belt; *G*, overarm locking levers; *H*, driving pulley to auto traverse; *I*, main-drive cone pulley; *J*, side and face cutter; *K*, cone pulley for auto traverse; *L*, flexible joint; *M*, telescopic sleeve; *O*, cone pulley on machine countershaft; *P*, drop worm; *Q*, knee-raising screw; *R*, knee; *S*, drop-worm control; *T*, trip and dead-stop lever; *U*, parallels under work; *V*, cross traverse handle; *W*, knee-raising handle; *X*, machine vice; *Y*, table; *Z*, slot for automatic trip and dead-stop dogs; Σ, table-locking screw.

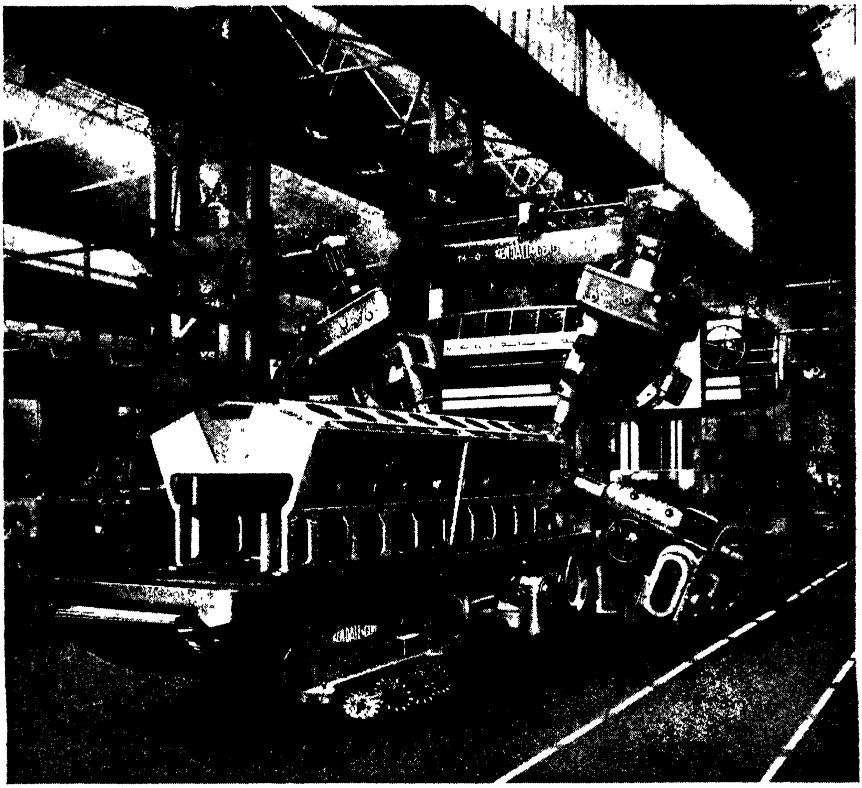


FIG. 13.—LARGE PLANO-MILLING MACHINE WITH FOUR CUTTERS (*Kendall & Gent.*)

inclined spindles, and each upright also may receive saddles. Simultaneous attack with as many as ten spindles thus becomes practicable. Double-faced machines are constructed with cross-rail and saddles at the rear of the standards as well; the table thus progresses with its load past a set of roughing mills, then past a set which finish.

Fig. 13 shows a large modern plano-miller machining 16-cylinder V-type Diesel engine cylinder block, using four milling heads. Each milling head is equipped with its own 25/25 h.p. motor and separate motors are used for elevating the cross-slide, traversing the table, and traversing the milling heads. Speeds and feeds are of wide range to enable tungsten-carbide and high-speed steel cutters to be used. Rapid power traverses are provided for setting purposes.

The machine is entirely foolproof in operation, all motions being controlled from pendant push-button station.

Vertical Machines

The vertical attitude for a spindle is the most convenient for a great many sorts of cutting with end mills, and sometimes side ones, because it is easier to hold the work suitably, and to watch cutting. The smallest verticals undertake die-sinking, grooving, and surfacing of all sorts; larger ones deal with any kind of casting or forging, to surface, groove, T-slot or otherwise machine. Cams and any profiles are tooled with controlling mechanism moving the table, or a supplementary one on it.

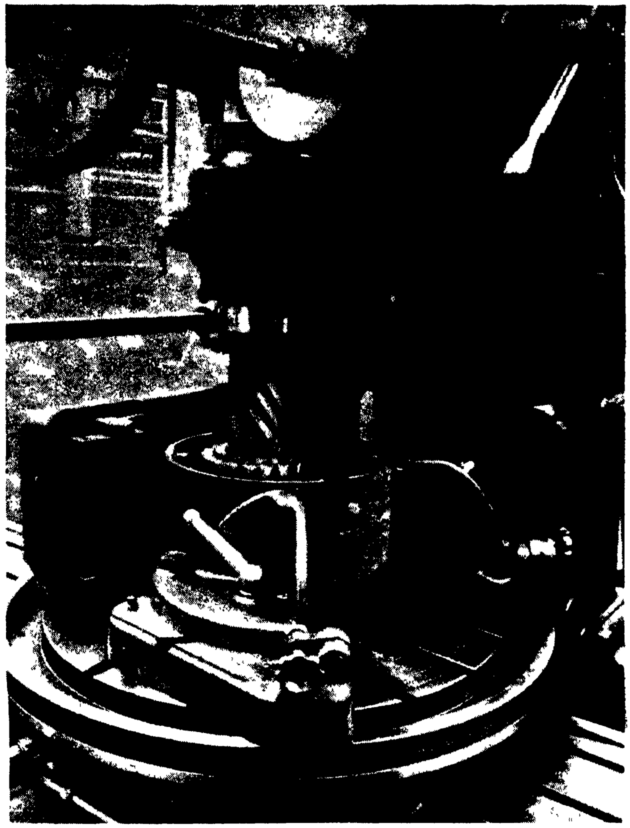


FIG. 14.—GANG MILLING A STATOR FRAME ON A HERBERT VERTICAL MACHINE

Gang Milling on a Vertical Machine

The gang mill visible in Fig. 14 lowers into the work—a stator frame—to finish the seatings. The lower end of the arbor runs in a steady which reaches down from the bearing. A three-part fixture holds the casting on the rotary table.

Continuous Rotary Machines

A fairly recent practice is that of clamping a circle of repeat components on a large circular table, the revolution of this being sufficiently slow to permit of removing finished units when they come to the front, and substituting untooled ones. There is either one spindle with single or gang cutter, or two spindles, the second being for finishing. The principle of this operation can be seen in Fig. 15. Time is saved by having quick-acting clamps or pneumatically operated grips

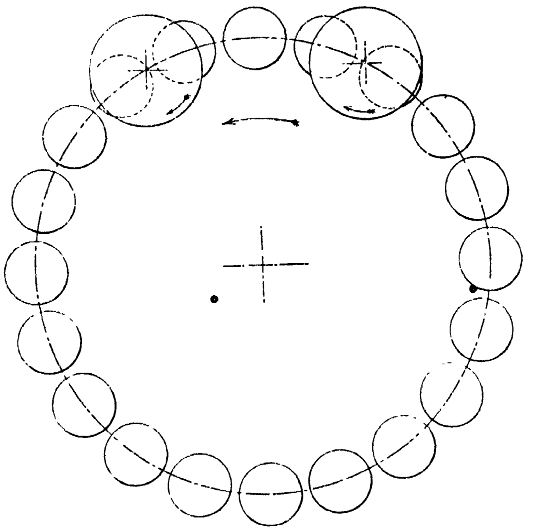


FIG. 15.—PLAN DIAGRAM ILLUSTRATING PRINCIPLE OF CONTINUOUS MILLING, WITH ROUGHING AND FINISHING CUTTERS

on the fixtures. Besides vertical-spindle styles, horizontal "drum" machines are used, single- or double-ended.

Station Millers

Some shapes cannot be milled on the continuous machines, but must be given an infeed towards the cutter, and withdrawn. The station method also makes use of a circular table, which moves back on a slide, indexes to the next station, and feeds it again, unloading and loading without stopping.

Travelling-column Millers

These are suitable for work of any dimensions.

The work can be milled, drilled, bored, and faced on large machines with spindle saddle feeding vertically on a column which feeds along a bed.

Special-purpose Machines

Milling is of such varied application that a number of special kinds of machines is built to use cutters in a particular manner, with one-purpose holding equipment. Briefly, the principal forms are: for keyways, with quick-action shaft-holding V-blocks; for fluting twist drills, a cutter working from each side, and the drill fed along and given a spiral motion; for profiles, which are cut by the control of a master shape, causing either the work or the cutter to move in the desired path—cams are included under this heading; for worms and screws, the blank rotating and the cutter driven at suitable speed, a traverse movement is imparted, thus producing a thread; for teeth, a mill cutting racks, spur, spiral, wormgears;

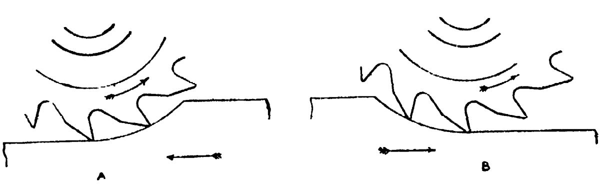


FIG. 16.—METHOD OF FEEDING WORK AGAINST CUTTER

A is the better way. If done as at *B*, the edges come down on the scale.

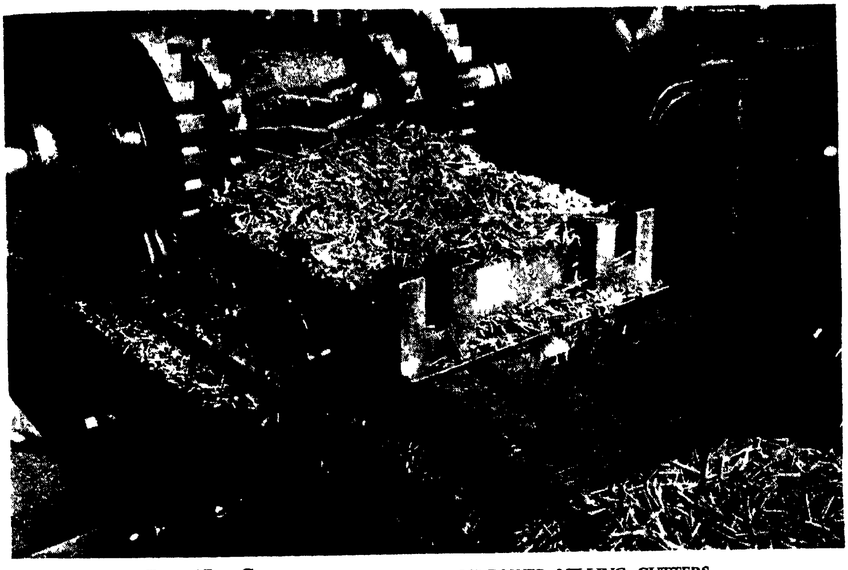


FIG. 17.—GANG MILLING WITH HIGH-POWER MILLING CUTTERS

Milling a steel cross slide for Herbert capstan lathe. These slides are machined at one setting. Feed, 1 in. per minute. A finished slide is shown.

FIG. 18.—CUTTING SUCCESSIVE SLOTS BY SETTING THE TABLE ACROSS AFTER EACH PASS THROUGH

Milling slots in brass strips. Several are held in the vice at once. (*Buck & Hickman, Ltd.*)

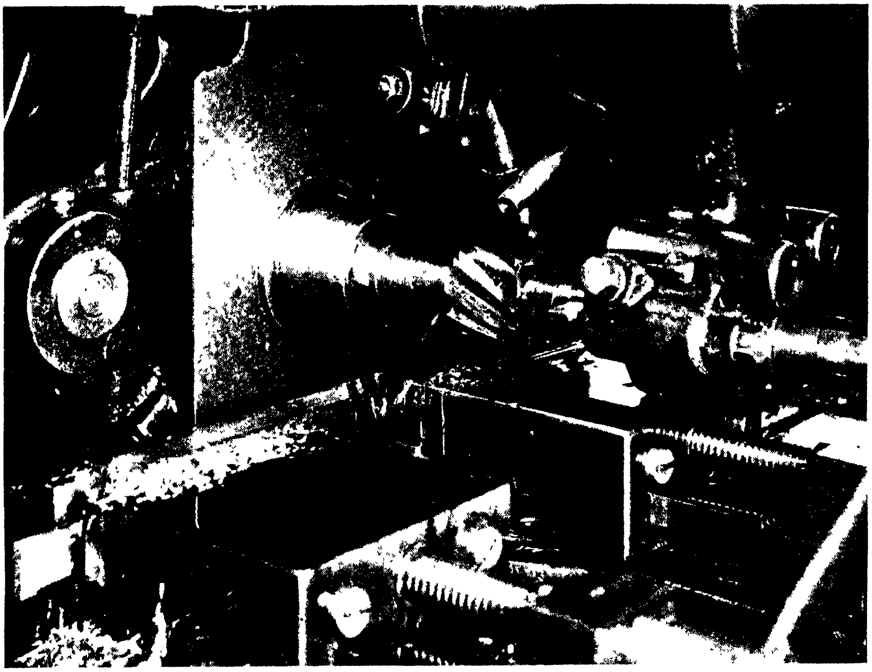


FIG. 19.—TWO VICES TAKE A LONG STRIP FOR MILLING

Rough milling for gauge work at Buck & Hickman's on Brown & Sharpe universal milling machine.

this may be done on a universal miller, or a gear cutter proper. The big factories making locomotives, automobiles, agricultural, spinning, and other machinery employ a large number of single-purpose millers, designed solely for specific components.

Methods of Holding Work

The same general methods of holding work on other machines apply to millers, such as using bolts, clamps, packings, V-blocks, stops, angle plates, magnetic chucks, vices. Owing to the greater range of milling operations, however, other appliances come into common use, for obtaining rotary or part rotary motion, setting to angles, pitching in a linear or a circular direction, while fixtures for repeat pieces are used in immense quantities.

Thin Work

It is more difficult to mill successfully a thin piece than a thick one, first, to hold it firmly without distortion, and to apply the cutter so that lifting or vibration will not occur. As a rule most milling is done with the work feeding

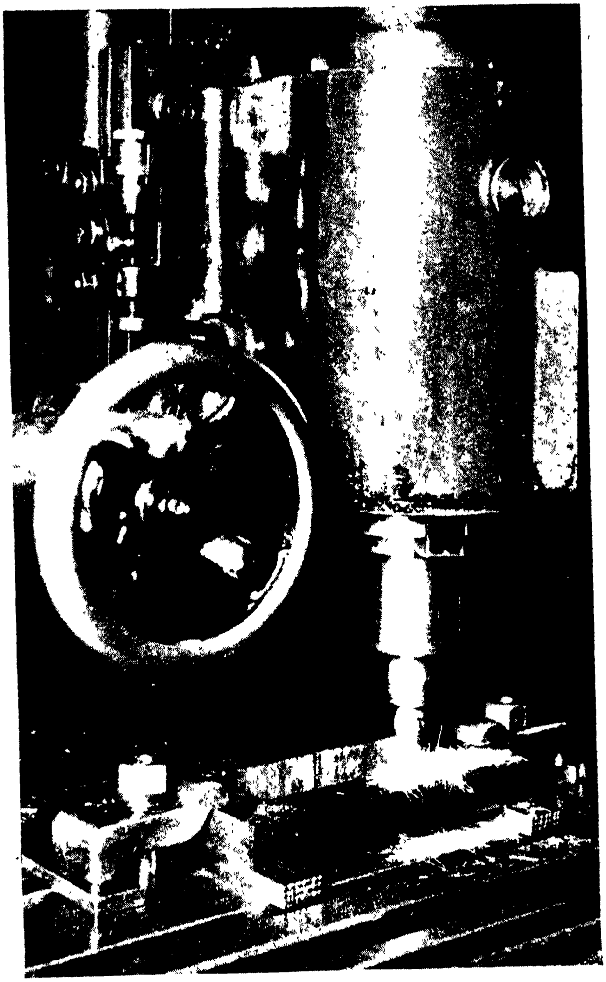


FIG. 20.—ROUTING OUT A DIE ON A VERTICAL MILLER
Using two-lipped fast helical end mill on Brown & Sharpe machine. (*Buck & Hickman, Ltd.*)

in the opposite direction to that of the cutter rotation, Fig. 16, *A*, to prevent the work from drawing in, with jerky progression. The advantage is also gained of cutting up into clean metal, and prising off the scale instead of continually bringing down the edges on it—to their detriment. Thin stuff will lie better under the opposite feed direction, Fig. 16, *B*, which is likewise good for some deep slotting. The table gib screws should be set up rather hard to partially compensate for lost motion, or a counterweight can be hung in such a way as to hold back the table.

Fixtures

A jig, as employed in drilling and boring machines, holds work and guides the tools, but a fixture only performs the first-named duty. The various systems of location in fixtures are by: contact spots touching rough or machined parts of the piece, adjustable screw pads, spring plungers which are allowed to float against the surface naturally, then are tightened; Vs or curves supporting round sections, arbors or holes. Construction should afford rigidity, ease of cleaning out the chips, and rapid handling of the clamps. The latter may slide, swing, or hinge back for unloading. When practicable, the cutting pressure

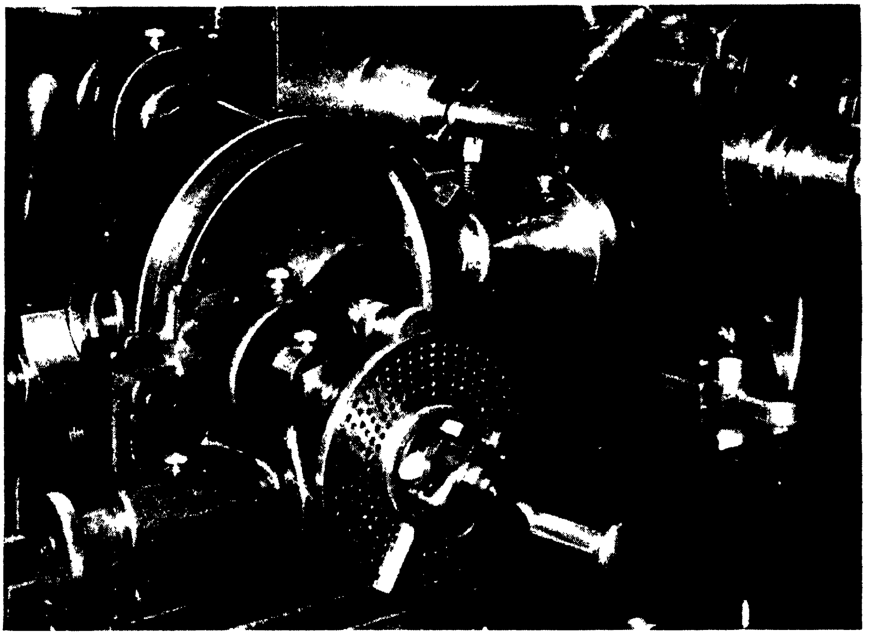


FIG. 21.—CUTTING A SPUR GEAR ON A MILLING MACHINE WITH INDEX CENTRES

A form cutter is used and the work is indexed the required amount by means of the spiral index head. The work is held on a mandrel and mounted between centres. (*Buck & Hickman, Ltd.*)

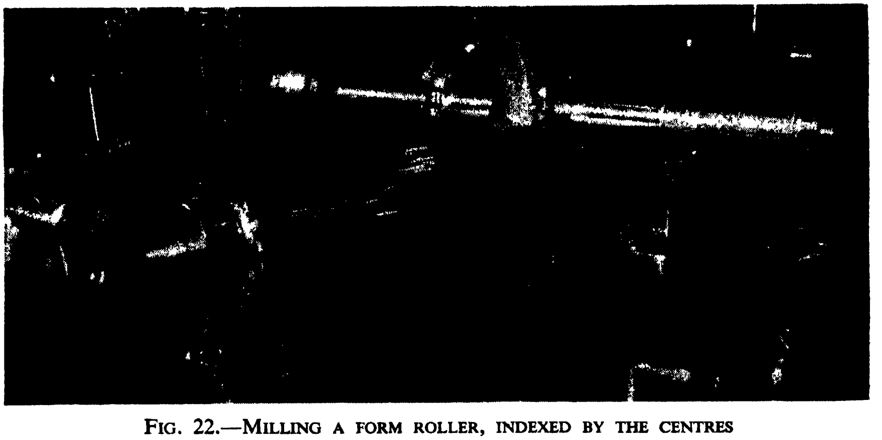


FIG. 22.—MILLING A FORM ROLLER, INDEXED BY THE CENTRES

The work is indexed as in Fig. 21, but held between the three-jawed chuck and the back centre. Note the wooden blocks placed to prevent damage to the table when setting up the job. Brown & Sharpe plain milling machine. (*Buck & Hickman, Ltd.*)

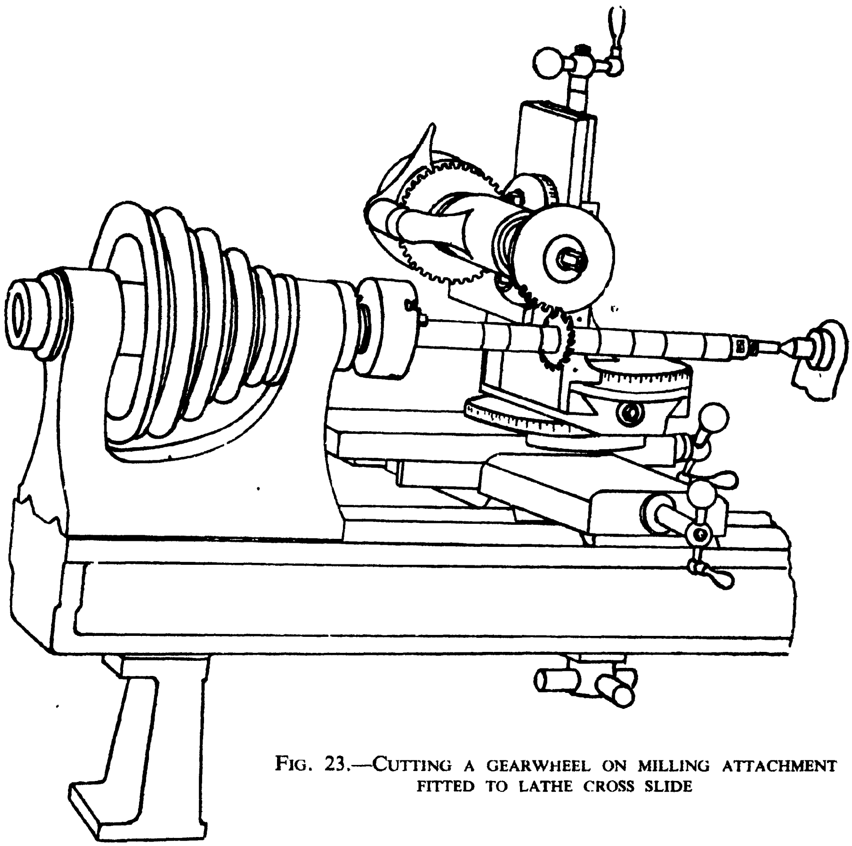


FIG. 23.—CUTTING A GEARWHEEL ON MILLING ATTACHMENT FITTED TO LATHE CROSS SLIDE

should be towards a solid portion of the fixture, not against a clamp. A fixture holds one casting or forging, or a batch, while on the manufacturing, plano-type, continuous and station machines, a string of fixtures takes similar items. Or, occasionally, two or three shapes will be held, for convenience of keeping output of respective parts going uniformly through the shops. Some fixture outfits are devised to hold work in another position, after passing it along for one cut.

Milling Examples

Varied specimens may be compared in the illustrations. Fast gang operation (Fig. 17) makes use of surfacing and slotting mills, the former having nicked edges to break up the chips, thereby easing the cutting, and allowing the swarf to escape more freely. The alternative to gang operation (Fig. 18) shows slots being milled in a set of brass strips, and the table has to be moved over for each

pass. Fig. 19 has two vices set up to take a long strip. A two-lipped helical cutter in a vertical machine routs out a die (Fig. 20).

Using Index Centres

With a dividing head and tailstock placed on the table, any kind of toothed subject may be pitched round for successive passes, or if a geared connection be made to the table screw, a spiral will be the result, as for gears, mills, twist drills, and counterbores. Spur-gear cutting is the operation visible in Fig. 21, pitching being effected by the crank handle and index plate seen. A form roller appears in Fig. 22. Index centres for "manufacturing" are made in dual or triple form, the spindles indexed simultaneously by one handle, and the cutter arbor drives two or three mills spaced as necessary. For further details of indexing, see page 344.

Milling Attachments

Milling may also be done on lathes by the employment of a milling attachment, of which there are many types. These may be divided into two classes: those using the machine spindle for the cutters, and those using a spindle on the attachment and driven from a special countershaft. The cutter consists of a small end mill of suitable diameter, or may even be a short twist drill with its lips ground to cut a flat bottom to the slot. The work is set for height by means of the vertical slide, which supplies the only additional motion required to render the toolpost (or job clamped thereon) adjustable to any position. It is often possible to arrange matters on a lathe, without an attachment, so that jobs similar to the above can be done, but the method is not too satisfactory on account of the necessary odd packings to obtain the correct centre height.

Gear Cutting with the Attachment

It is possible to cut gears on some of these attachments, using either a regular dividing head, as depicted in Fig. 23, or, as is quite usual, one of the lathe change wheels containing the same number, or some multiple of the number, of teeth in the required gear.

It should be noted in this connection that it is preferable that the arbor carrying the cutter is driven by the taper hole in the headstock spindle in the same manner as a drill. Failing this, a chuck can be used, as in Fig. 23, or if the arbor is run between centres a rigid drive should be obtained against both back and front of carrier to obviate undue chatter when cutting.

Short stiff arbors are indicated whenever possible.

The attachment shown in Fig. 23 is a complex one, and may be used for almost any small milling work that can be fixed on an arbor. In the case of attachments fastened on the slide rest, their greatest use will be found in the cutting of keyways and in the milling of squares or hexagons on special bolt heads, etc. To this end their speed is usually fairly high, and they may sometimes be used for drilling transverse holes in a spindle held between centres.

CEMENTED CARBIDE-TIPPED CUTTERS

Milling cutters both of the solid and inserted-tooth types having the cutting areas tipped with carbide are coming into increasing use. The three types of carbide used are tungsten carbide, tantalum tungsten carbide, and molybdenum titanium carbide.

The carbide tips are prepared by a "sintering" process, and are brazed on to the cutting tools by either one of the four following processes: torch brazing, furnace brazing, electric resistance tool brazing, or high-frequency brazing.

It is claimed by the leading manufacturers of cemented carbide-tipped tools that by accurate use of these tools the output of work obtainable from machine tools can often be increased by several hundred per cent.

In this connection, various milling operations using cemented tungsten-carbide-tipped cutters are shown in Figs. 24, 25, 26, and 27. Of special interest is the machining of the face of a 65-ton tensile-steel ingot, using a cemented tungsten-carbide-tipped face mill, as shown in Fig. 27. Speeds in the region of 20 in. per minute were used on this operation.

Since cemented carbide-tipped tools are finding increasing use in engineering production work, a special article dealing with these tools has been included in this work, and will be found on page 465.

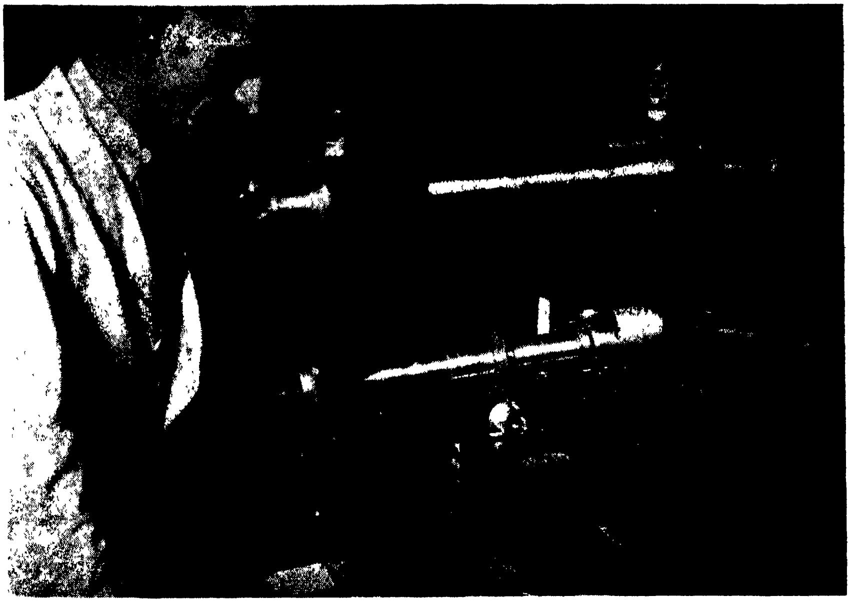


FIG. 24.—SLOTTING AN ALUMINIUM AND BRASS COMPONENT, USING A TUNGSTEN-CARBIDE SLOTTING CUTTER ON A HIGH-PRODUCTION MILLING MACHINE (*Protolite, Ltd.*)

FIG. 25.—MILLING AN ALUMINIUM CASTING, USING A POSITIVE RAKE, CEMENTED TUNGSTEN-CARBIDE FACE MILLING CUTTER (*Protolite, Ltd.*)

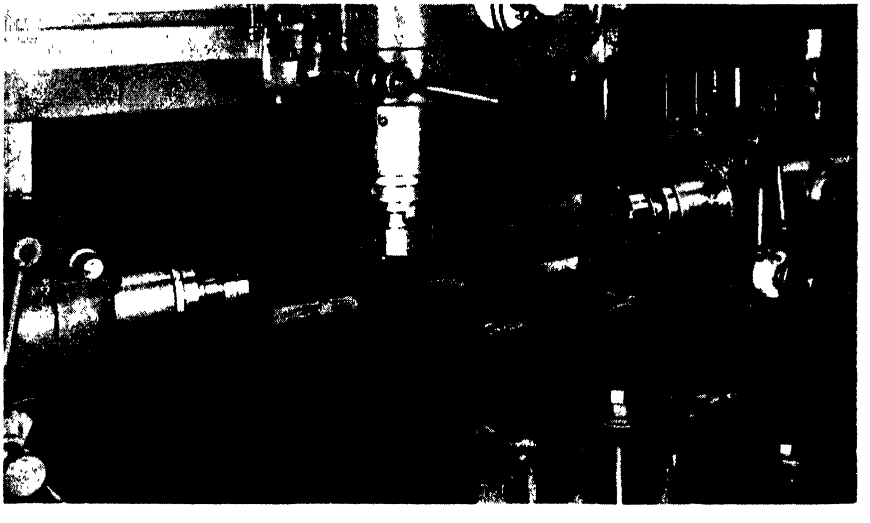


FIG. 26.—MILLING THREE FACES ON A CAST-IRON BED PLATE, USING THREE CEMENTED TUNGSTEN-CARBIDE-TIPPED FACE MILLING CUTTERS (*Protolite, Ltd.*)

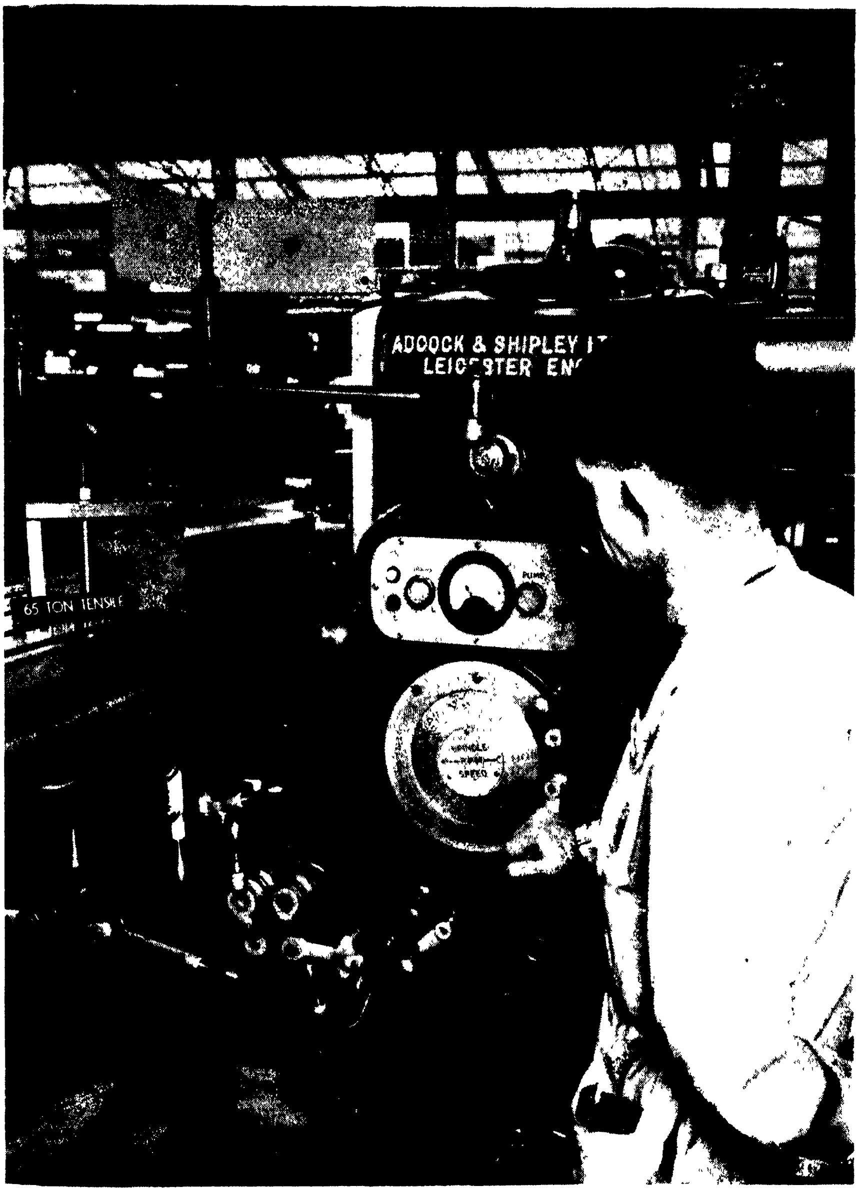


FIG. 27.—MACHINING A FACE OF A 65-TON TENSILE-STEEL INGOT, USING A CEMENTED TUNGSTEN-CARBIDE-TIPPED FACE MILL

Speeds in the region of 20 in. per minute were used on this operation. (*Protolite, Ltd.*)

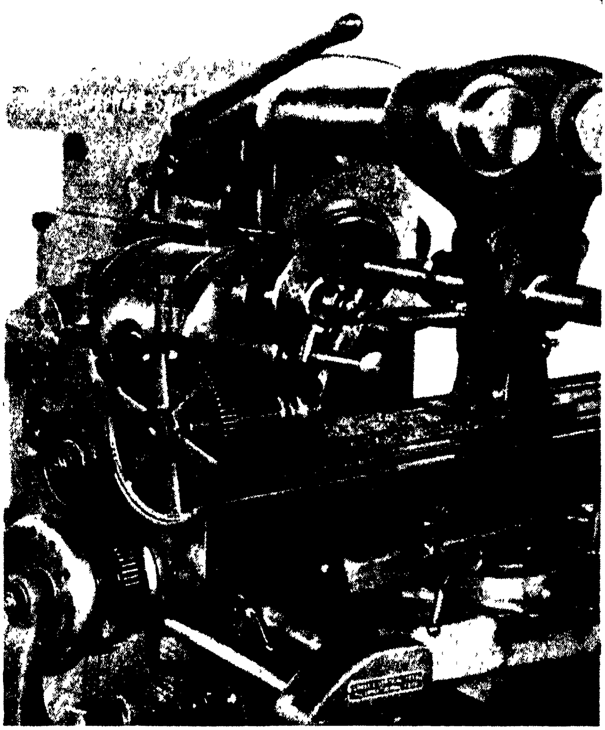


FIG. 28.—TRUNNION-TYPE HEAD-CUTTING TWIST DRILL
(*Buck & Hickman, Ltd.*)

THE UNIVERSAL SPIRAL INDEXING HEAD

One of the most important operations done on a milling machine is the indexing and rotation of work in conjunction with movements of the table. This is done by means of the universal dividing or indexing head, which is used for cutting spirals, cams, graduations, and endless other jobs.

Two forms of Universal Index Heads (Brown & Sharpe), the trunnion and quadrant types, are shown in Figs. 28 and 29. The head is a hollow casting, in which is mounted a spindle, connected to an index crank through a worm and wheel. Fig. 30 shows the internal construction of a Brown & Sharpe head.

Fig. 28 shows the usual position of the head on the milling-machine table, but Fig. 31 shows the head placed in the centre of the table, whilst Fig. 32 shows a false baseplate to enable the operator to set the head at right angles to the table.

Internal Mechanism of the Head

The headstock spindle passes through the head and is held in position by a nut at the small end (Fig. 30). The front end is threaded, like the nose of a lathe, and has a taper hole to take centres. It is rotated by a wormwheel, which is driven by a hardened worm, located on the shaft to which the index crank is fastened. Through gearing, the index plate and worm can be driven together from the table feed screw when the index pin is in position in any hole on the plate.

Operating the Head

When the worm is turned by means of the index crank, indexing may be accomplished. When the worm is geared to the table feed screw, spiral milling,

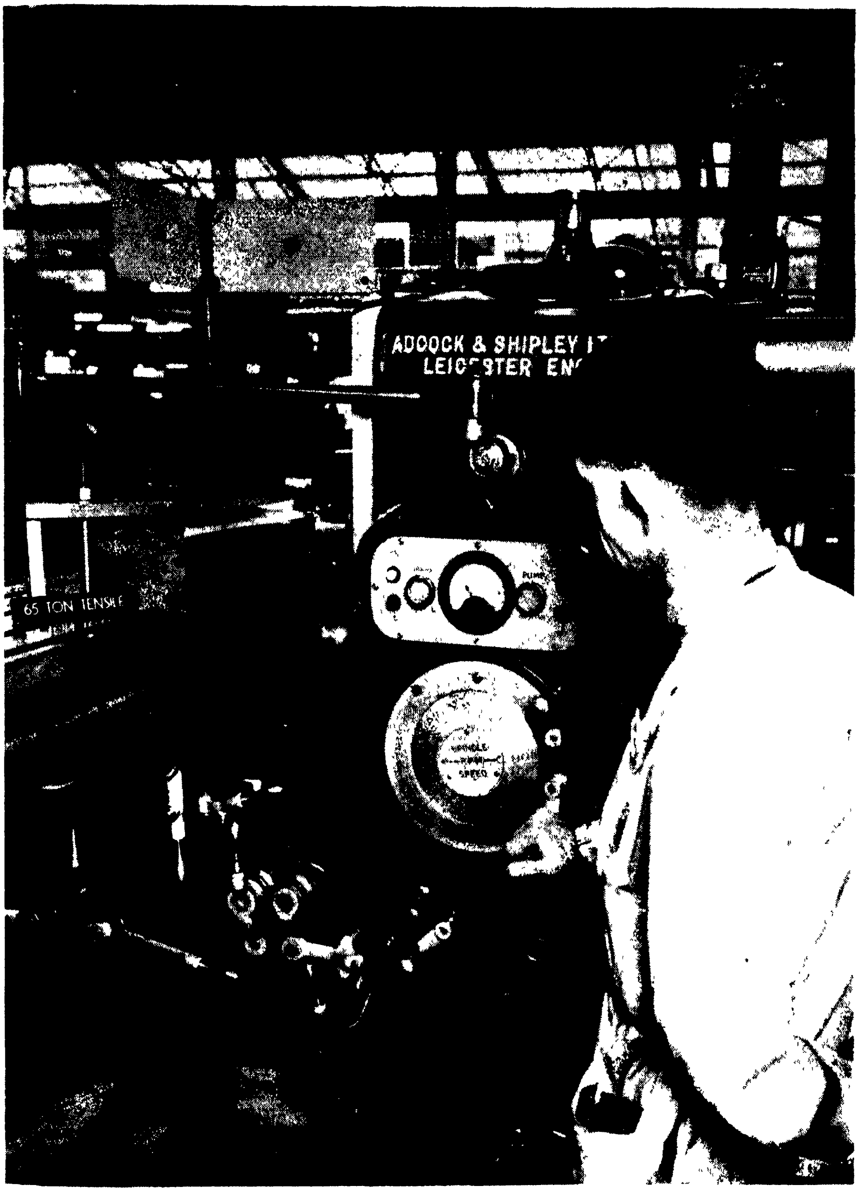


FIG. 27.—MACHINING A FACE OF A 65-TON TENSILE-STEEL INGOT, USING A CEMENTED TUNGSTEN-CARBIDE-TIPPED FACE MILL

Speeds in the region of 20 in. per minute were used on this operation. (*Protolite, Ltd.*)

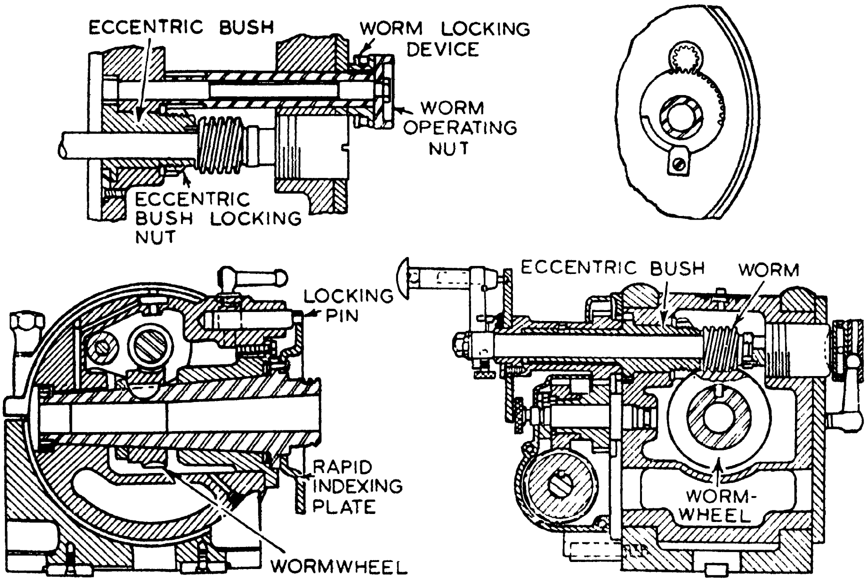


FIG. 30.—DETAILS OF INDEXING HEAD

circle: Plate 1—15, 16, 17, 18, 19, 20; Plate 2—21, 23, 27, 29, 31, 33; Plate 3—37, 39, 41, 43, 47, 49.

The change gears with their number of teeth are as follows: 24 (2 gears), 28, 32, 40, 44, 48, 56, 64, 72, 86, and 100.

Graduated Index Sector

Without the graduated index sector, much care would have to be exercised in counting the holes in an index plate when indexing to obtain any given number of divisions. Such a sector enables the correct number of holes to be obtained at each indexing with but little chance of error. Fig. 33 shows that the sector consists of two arms, which may be spread apart when the screw *A* is slightly loosened. The correct number of holes can be counted and the sector set to include them; or, better still, the graduations on the dial may be used in connection with the tables supplied with every head.

Adjusting the Index Crank

The index crank is circumferentially adjustable. This is shown in Fig. 34. It is frequently desired to make delicate adjustments, or to bring the index pin to the nearest hole without disturbing the actual setting of the work. To adjust the index crank after the work has been placed in position, turn the thumbscrews *A–A* (Fig. 34) until the pin enters the nearest hole in the index plate. To rotate the

work relative to the index plate, both the stop pin at the back of the plate and the index crankpin should be engaged, the adjustment being made by means of the thumbscrews as already explained.

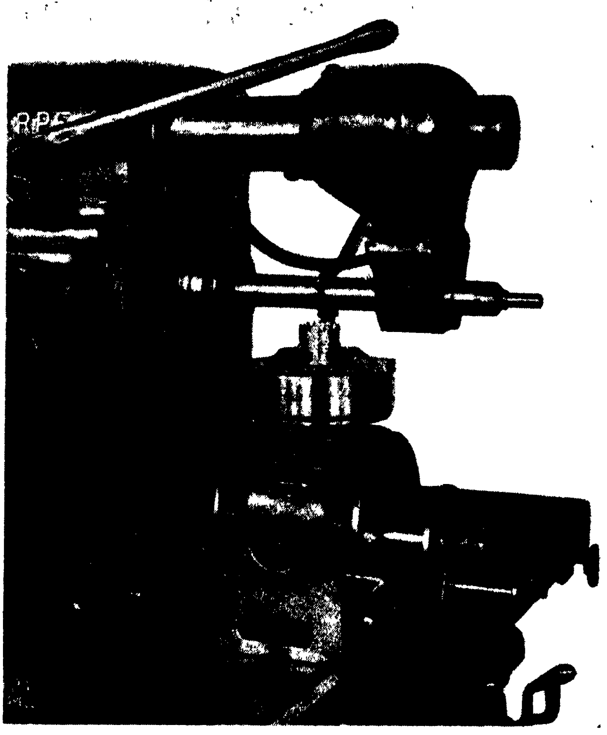


FIG. 31.—HEAD IN OPERATION AT TABLE CENTRE
(*Buck & Hickman, Ltd.*)

Throwing Worm out of Mesh

When it is desired to turn the spindle by hand and index work by means of the plate on the nose of the spindle, it is necessary to disengage the driving worm (Fig. 30). To do this, turn the worm-locking device by means of the pin wrench supplied with the head about a quarter-turn in the reverse direction to that indicated by an arrow stamped on the device. This will loosen the nut that clamps the eccentric bushing; then with the fingers turn both worm-locking device and worm-operating nut at the same time, and the eccentric bushing will revolve and disengage the worm from the wheel. To re-engage, reverse the operation.

Effect of Change in Angle of Elevation

If the angle of the headstock spindle is changed during operation, the spindle must be rotated to bring the work back to the correct position, remembering that when the spindle is elevated or depressed, the worm-wheel is rotated about the worm, and the

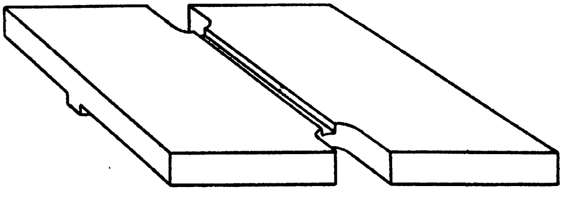


FIG. 32.—FALSE BASEPLATE TO ATTACH HEAD TO TABLE AT 90°

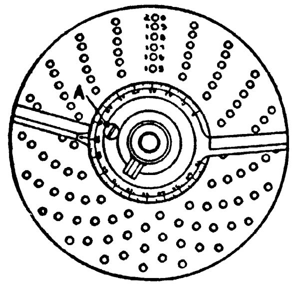


FIG. 33.—DIVISION PLATE SECTOR

effect is the same as if the worm were turned. Milling permits no errors, therefore this precaution is emphasised.

Indexing

The main duty of the head is to index or divide the periphery of the work into a number of given parts. This is accomplished by means of the index crank and the index plates furnished with the head; or, in the case of more common divisions, by means of the rapid-index plate fastened to the nose of the spindle. There are two practical and accurate methods of indexing, known as "plain" and "differential." The plain method is by using the holed plates, the disadvantage being that some divisions cannot be obtained, whilst the differential method is the additional use of change-gear wheels to enable the division plates also to be governed. With plain indexing the division plate is fixed in a predetermined position, whilst with the differential system the division plate is attached to the differential gearing.

Plain Indexing

The wormwheel on the spindle contains forty teeth and the worm has a single thread; therefore for every turn of the index crank, the wormwheel is advanced one tooth, or, in other words, the spindle makes one-fortieth of a revolution. This ratio must be remembered, as it is used for all indexing calculations. If the crank is turned forty times, the spindle and the work attached will make one complete revolution. To find how many turns of the crank are necessary for a certain division of the work, forty is divided by the number of divisions desired on the work.

For example, supposing that after running the cutter along a shaft (so producing a flat), the crank handle is turned exactly ten times and the cutter again run along the shaft, it will readily be seen that the second cut will be at right angles to the first, for 40 divided by four divisions = 10 turns of the crank. If the crank is turned another ten times and a cut taken, and then another ten, the shaft will either become square, or at least will have four flats on it at 90° each. We have divided the circle into four equal parts. Should the crank handle be revolved only five times instead of ten, we shall produce an eight-sided figure. This is very simple, but gets a little more complicated as we proceed.

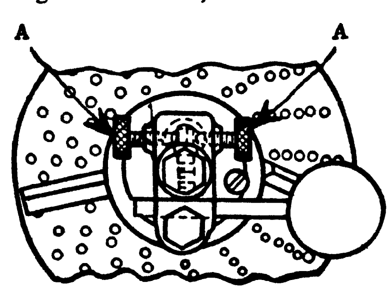


FIG. 34.—INDEXING CRANK ADJUSTING SCREWS

When we desire to produce a hexagon, or six-sided figure, the formula is

$40 \div 6 = 6\frac{2}{3}$; therefore to form the hexagon the crank must be turned six complete revolutions and two-thirds of a revolution. To carry this out with ease, the head is provided with a division plate containing several circles of holes that have been carefully spaced, so that the crank can be held, or stopped, in any desired place. As there is no plate with only 3 holes, we choose a circle with a number of holes which is a multiple of 3, for example, 33, and make the following calculation: $\frac{2}{3} \times \frac{11}{11} = \frac{22}{33}$. Therefore, if the 33 circle is chosen and the first cut taken with the crankpin in the first hole (zero), it will only be necessary to revolve the crank six turns and 22 holes from the place where the pin was last to make the next cut spaced at one-sixth of the periphery of the work. The result would have been exactly the same had we chosen a 39-hole circle or an 18-hole circle, by spacing 26 or 12 holes respectively.

At times, the fraction is of large terms; therefore it should be reduced so that its denominator will represent a number of holes that is available.

Another example: if seven divisions are desired, 40 divided by $7 = 5\frac{5}{7}$ turns of the handle for each division. Multiplying by the common multiplier 3, we have $\frac{5}{7} \times \frac{3}{3} = \frac{15}{21}$. Hence, for one division of the work, the index crankpin is placed in zero of a 21-hole circle and the crank given 5 complete turns, and then moved ahead 15 holes. We could have used 35 holes in a 49 circle had we chosen.

Indexing in Degrees with the Plain Head

When it is desired to divide the circumference by degrees, it can often be carried out by plain indexing. One complete turn of the head is, of course, 360°; therefore one turn of the crank is $\frac{360°}{40} = 9°$. Following this method:

2 holes in the 18-hole circle $= 1°$
2 holes in the 27-hole circle $= \frac{2}{3}°$
1 hole in the 18-hole circle $= \frac{1}{2}°$
1 hole in the 27-hole circle $= \frac{1}{3}°$

Differential Indexing

The plain indexing head cannot divide certain divisions, and the differential head has been designed for this purpose. The principle of differential indexing is as follows:

If the plate, instead of being stationary, is fixed to the headstock spindle and moves with it, then when the crank handle is turned once, the plate will also turn in the same direction and perform one-fortieth of a revolution. In one complete revolution of the spindle, therefore, the spindle will have divided the circle into thirty-nine parts instead of forty, because the plate moving *with* the crank will have *lost* one-fortieth at each turn. If the plate and crank handle are arranged to move in opposite directions, then the circle will be divided into forty-one parts instead of forty, because the spindle will *gain* one-fortieth per revolution of the crank handle. The crankpin will, of course, be placed in exactly the same (zero) hole every time. This hole gradually performs a circuit of its own, either with or against the spindle as required, and it is on this basis

that differential indexing is carried out. The change wheels supplied with the Brown & Sharpe differential indexing head will give over 1,000 divisions, more than enough for any ordinary purpose. By inserting various gears and changing direction, we can obtain all the ratios mentioned. Tables are supplied with every head to save the operator working out the calculations, but it is as well to know how it is done, so as to be fully acquainted with the device.

Determining the Wheels to use in Differential Indexing

The formula for gearing is as follows:

N = Number of divisions required.
H = Number of holes in division plate.
n = Number of holes taken at each indexing.
V = Ratio of head = 40 (on Brown & Sharpe head).
x = Ratio of train of gearing between spindle and plate.

$$\left.\begin{array}{l} S = \text{Gear on spindle} \\ G_1 = \text{First gear on stud} \end{array}\right\} \text{drivers.}$$

$$\left.\begin{array}{l} G_2 = \text{Second gear on stud} \\ W = \text{Gear on plate} \end{array}\right\} \text{driven.}$$

$$x = \frac{HV - Nn}{H} \text{ if } HV \text{ is greater than } Nn.$$

$$x = \frac{Nn - HV}{H} \text{ if } HV \text{ is less than } Nn.$$

$$x = \frac{S}{W} \text{ for simple gearing.}$$

$$x = \frac{SG_1}{G_2W} \text{ for compound gearing.}$$

With differential indexing it is not imperative to select any particular division plate, but it is best to choose one with a number producing factors that are contained in the change-gears. If the number of holes in the division plate H contains a factor not found in the gears, it will be difficult, and perhaps impossible, to obtain the correct ratio in the wheels used between the spindle and the division plate x, unless the factor is cancelled by the difference between HV and Nn, or unless the number of divisions N contains the factor.

When HV is greater than Nn, and the gearing is simple, use *one* idler only; if the gearing is compound, use no idlers.

When HV is less than Nn, and the gearing is simple, use *two* idlers; if the gearing is compound, use one idler.

Select the number of holes taken at each indexing (n), so that the ratio of gearing will not exceed 6 to 1 on account of stress on gear teeth.

Before proceeding, the operator decides the division plate he will use and the number of holes he will index. From these he will be able to define x.

Example:

Divisions required, 319 (N)
Division plate selected, 29 (H)
Holes to be indexed (selected), 4 (n)
Ratio of gears required (x)
Ratio of head, 40 (V)

$$x = \frac{(N \times n) - (H \times V)}{H} = \frac{(319 \times 4) - (29 \times 40)}{29} = \frac{1276 - 1160}{29} = \frac{116}{29}$$

$$\frac{4}{1} = \frac{S}{W} \cdot \frac{12}{3} = \frac{3 \times 4}{1 \times 3} = \frac{SG_1}{G_2W} = \frac{(3 \times 24) \times (4 \times 16)}{(1 \times 24) \times (3 \times 16)} = \frac{72 \times 64}{24 \times 48}.$$

As shown in Fig. 35, wheel 72 goes on the spindle, wheel 64 goes on the stud (1st), wheel 24 goes on the stud (2nd), and wheel 48 goes on the division plate.

It is necessary to compound, as no wheels can be found to give a 4 to 1 ratio. HV being less than Nn and the gear compound, one idler is required.

Spacing Quarter Degrees with the Differential Head

Example: Wanted, the number of divisions required, the number of holes at each indexing for spacing $\frac{1}{4}°$, or 1,440 divisions.

Assume H to equal 33 and n to equal 1. Then

$$\frac{(1440 \times 1) - (33 \times 40)}{33} = \frac{120}{33} = \frac{64 \times 100}{40 \times 44}.$$

One idler is required.

Fractional Spacing

Required: a vernier to read to $\frac{1}{12}°$ or 5′, the scale being divided into degrees. Each vernier space can equal $\frac{11}{12}°$.

$$\frac{11 \times 1}{12 \times 360} = \frac{11}{4320} \text{ or } \frac{4320}{11} \text{ spaces in the whole circle} = 392\tfrac{8}{11} \text{ spaces.}$$

Assume $H = 18$ and $n = 2$, then—

$$\frac{(392\frac{8}{11} \times 2) - (18 \times 40)}{18} = \frac{720}{11} \times \frac{1}{18} = \frac{40}{11} = \frac{64 \times 100}{40 \times 44}.$$

One idler is required.

Graduating

The operation requires the use of a single-pointed tool, perhaps fastened in a fly-cutter holder, as shown in Fig. 36. The scale to be graduated is clamped to the surface of the table and the machine locked.

One turn of the index crank moves the spindle one-fortieth of a revolution, and if equal gearing is employed between the spindle and the table lead screw, the lead screw will likewise make one-fortieth of a revolution.

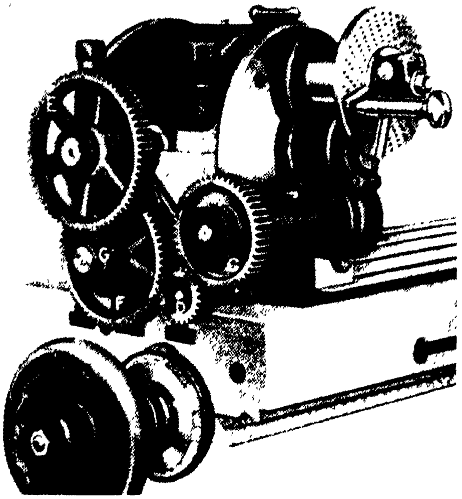


FIG. 35.—DIFFERENTIAL INDEXING—HEAD SET FOR 319 DIVISIONS

E, 72 teeth; *G*, 24 teeth; *F*, 64 teeth; *C*, 48 teeth; *D*, idler, 24 teeth.

If the lead of the table screw is 0·25 in., one turn of the index crank will advance the table an amount equal to 0·25 in. $\times \frac{1}{40}$, or 0·00625 in.

Suppose it is desired to graduate a scale with lines 0·0218 in. apart. If one turn of the index crank moves the table a distance of 0·00625 in., it will take more than one turn to move the table a distance of 0·0218 in. Hence—

$$\frac{0{\cdot}02180}{0{\cdot}00625} = 3\,\frac{0{\cdot}00305}{0{\cdot}00625}.$$

Taking the remainder, 0·00305 in., and referring to the specimen of the tables supplied with the head, we find that it is very near 0·0030488 in., which is the distance the table will be moved by using the 41-hole circle and indexing 20 holes. The error between the actual remainder and the amount given in the table is so small that it can safely be ignored.

It should be remembered in graduating that great care must be taken to prevent all backlash between the index crank and the table screw. The crank should always be turned in the same direction.

It is admitted that the ratio of gearing between the spindle and the table screw can be changed, but this complicates matters somewhat, and should be resorted to only when it is impossible to get accurate enough results with the method already described.

Spiral Milling

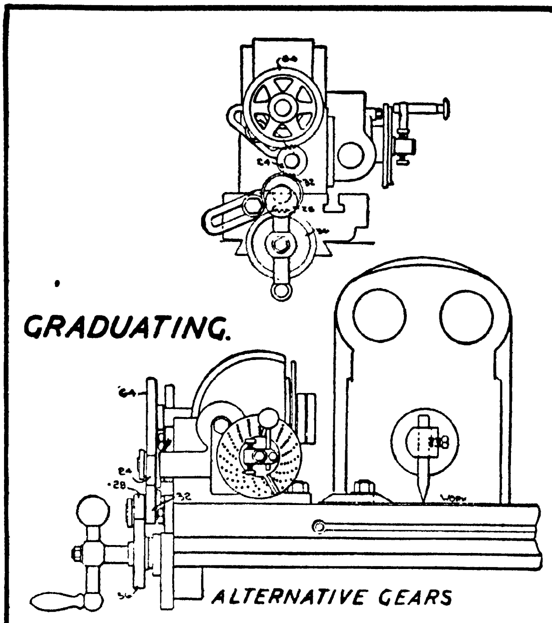
A further use of the differential head is to produce flutes or sides on cylindrical work that gradually perform a spiral on the work itself. This is carried out by attaching the head to the table screw by a train of gearwheels, so that the work revolves whilst the table is travelling under the cutter.

A gearwheel of predetermined size is placed on the table screw, behind the handle, in place of a collar usually fitted when the head is not required. Other gears are added as in previous examples. The gearing does not interfere with indexing, as, on the machine being stopped, the index crank can be moved to any desired position and so register any number of flutes or grooves.

Remembering that the 0·25-in. table screw turns the head spindle one-fortieth if the wheels used have an equal number of teeth, it will take forty turns of the

screw to revolve the spindle once, and, as the screw has four threads to the inch, the table will have travelled 10 in. This is the natural lead, and is called the "lead of the machine," and on this lead all spiral calculations are based. If the operator wishes to decrease the lead, he speeds up the head so that it turns more quickly in proportion to the table movement; if he wishes to lengthen the lead, say, to 20 in., he slows down the head to one-half.

According to the lead, so the angle of the cutter is set. This also applies to the diameter of the work, both having a direct bearing on the angle. A graphic example of the relation of the lead and diameter to the angle is to cut a piece of paper as shown in Figs. 37 and 38. The sides B and C are at right angles. The length of C represents the lead to be cut, and the length of the side B represents the circumference of the work (the length of A does not matter). If the paper is now cut into a right-angled triangle, using the outer ends of C and B, the side A will form the line the cutter will take in cutting the spiral; and the angle between A and C will be the angle at which the work must be set in relation to the cutter. The situation is clearly shown if the triangular piece of paper is laid around the shaft as in the illustrations.



WORM	56	48	64	64	56	48
1st ON STUD	28	24	32	32	28	24
2nd ON STUD	24	28	24	28	32	32
TABLE SCREW	48	56	48	56	64	64
ANY SUITABLE IDLER.						

FIG. 36.—GRADUATING

Without complicating the issue by small figures or fractional leads, let two pieces of paper be cut dealing with the natural lead of the machine, viz. 10 in., but using two different diameters of 2 in. and 4 in. respectively. Using approximate figures only, one triangle has the side B twice as long as the other.

First Triangle (Fig. 37):

Diameter of work, 2 in.

Length of C, 10 in. (lead of spiral).

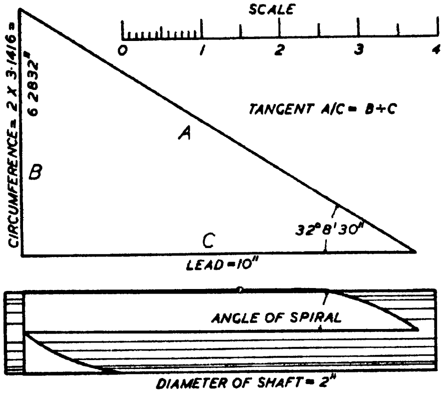


FIG. 37.—PRACTICAL ILLUSTRATION OF RELATION BETWEEN LEAD AND DIAMETER TO ANGLE

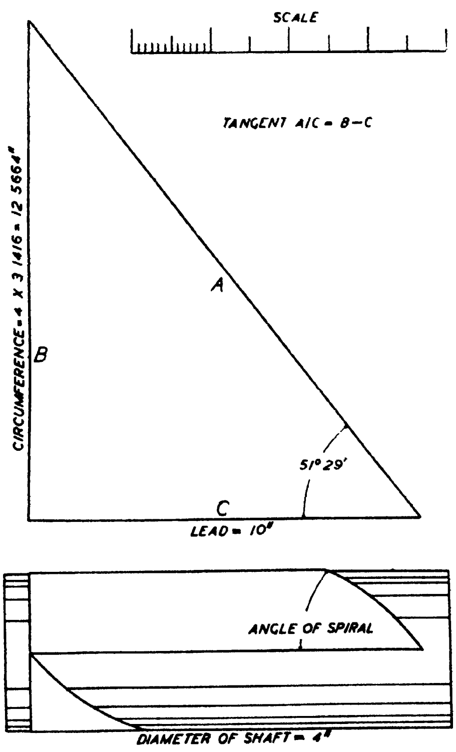


FIG. 38.—PRACTICAL ILLUSTRATION OF RELATION BETWEEN LEAD AND DIAMETER TO ANGLE

Length of *B*, 6·2832 in. (circumference of work).

Second Triangle (*Fig.* 38):

Angle *CA*, 32° 8½′ (angle of spiral).

Diameter of work, 4 in.

Length of *C*, 10 in. (lead of spiral).

Length of *B*, 12·5664 in. (circumference of work).

Angle *CA*, 51° 29′ (angle of spiral).

It is assumed the operator is versed in the solution of right-angled triangles; anyhow, it is necessary to find the tangent of the angle *CA* by dividing the length of *B* by the length of *C*, the result being the tangent of the angle. On reference to a set of trigonometric functions (not here shown) one finds the correct value of the angle, there being no necessity to find the length of *A*.

Tan $AC = B \div C$ (when one angle is 90°), therefore $\frac{6 \cdot 2832}{10} = 0 \cdot 62832$.

This figure is between tangents, 0·62811 and 0·62851; therefore the angle is, near enough, 31° 8½′.

It is pointed out that operators must study arithmetic, as nearly every job is preceded by a calculation of some kind.

Calculating the Gearing for Various Leads

Already it is known that the natural lead is 10 in.; therefore it is necessary to find the ratio of the lead required to the natural lead. Should the lead required be 12 in., then the ratio is 12 to 10, or, by dividing the required lead by the

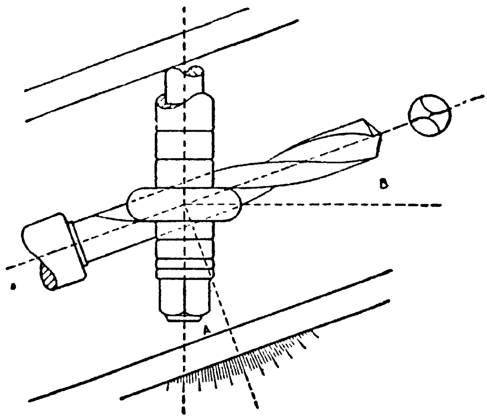


FIG. 39.—SPIRAL ANGLE RELATIONS

Angles A and B are always equal.

natural lead (10), the result is the ratio in the same manner: $\frac{12}{10} = \frac{6}{5}$ or 1·2 ratio.

Example:

What gear will be necessary to cut a lead of 27 in.?

$$\frac{27}{10} = \frac{9}{5} \times \frac{3}{2} = \left(\frac{9}{5} \times \frac{8}{8}\right) \times \left(\frac{3}{2} \times \frac{16}{16}\right) = \frac{72}{40} \times \frac{48}{32}.$$

72 and 48 are the driven gears and 40 and 32 the driving gears.

Another example, but with a lead of 12 in.:

$$\frac{12}{10} = \frac{72 \times 32}{48 \times 40} = \frac{\text{wheel on worm} \times \text{wheel on stud 2}}{\text{wheel on screw} \times \text{wheel on stud 1}}.$$

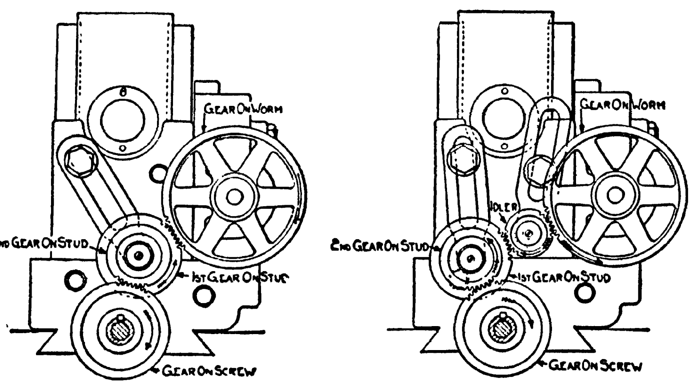
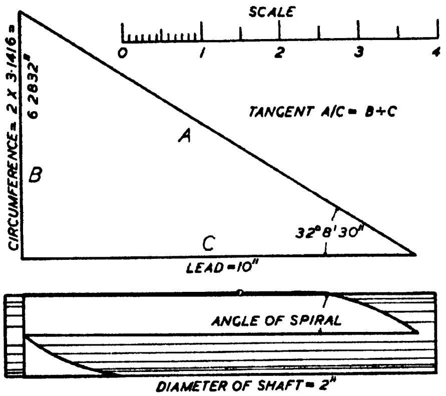


FIG. 40.—SPIRAL AND CAM CUTTING GEARS

Compound gearing between "head" and table lead screw. Note interposition of "idler" to change direction of division plate.



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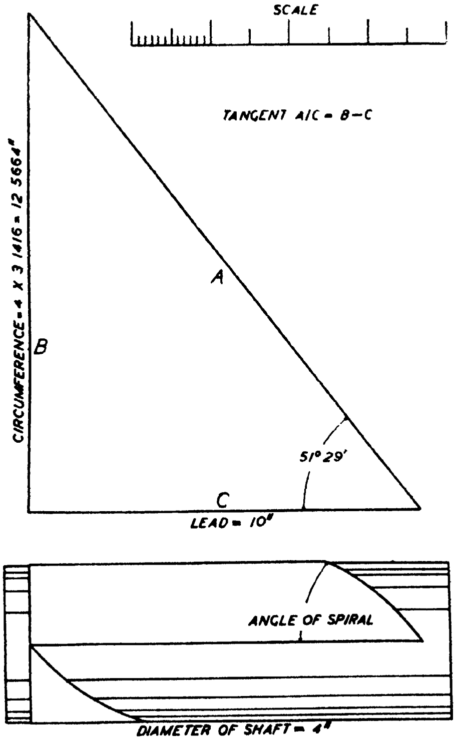

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Diameter of work, 4 in.

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Calculating the Gearing for Various Leads

Already it is known that the natural lead is 10 in.; therefore it is necessary to find the ratio of the lead required to the natural lead. Should the lead required be 12 in., then the ratio is 12 to 10, or, by dividing the required lead by the

far greater accuracy. The operation is carried out with the head geared to the table of the machine in the usual manner, but in this instance the angle to which the head is set plays a very important part.

Owing to the great variety of lifts used on cams, wheels to bring about the various leads would be out of all proportion to economic production. The usual change wheels are used in practice and leads of very great accuracy are obtained by setting the head and the cutter mandrel to specified angles. It is with these angles that this section will deal.

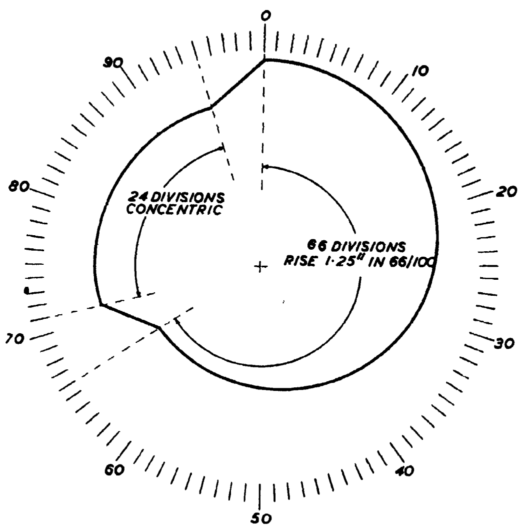

FIG. 42.—CAM LAYOUT
Showing one rise and one concentric section.

To explain the method, let a circular blank be fixed on the head with the attachment and head set in relation to one another as Fig. 41, *B*. Gear the head for a lead of 2 in. The cutter in use is an end-mill, only the sides being used. Start the machine, and in one revolution of the head the cutter will have cut into the blank 2 in., because the work will have advanced towards the cutter 2 in. during one revolution. Keep in mind the fact that only the side of the cutter is used. Now let the head and attachment be set as shown in Fig. 41, *A*, and with a similar blank on the head start the machine. The 2-in. lead will take the work towards the cutter, but the cutter will not remove any metal because the work does not get any nearer to the side of the cutter. In Fig. 41, *B*, the cutter cuts in the maximum distance, but in Fig. 41, *A*, the cut in is zero. From this it will be seen that by setting the head and spindle to some intermediate degree between 0° and 90°, any lead less than 2 in. can be arranged. The maximum cut in is the lead arranged with the aid of the gears, whilst leads below that maximum are determined by the angle of the head and cutter spindle. Fig. 41, *C*, shows the head in an intermediate position.

The arranging of the angles, etc., is quite a simple matter with a little practice and a knowledge of figures. For greater accuracy, first choose a lead nearest but larger than the desired lead to be cut, the reason being that the operator has the whole 90° at his disposal to attain finality. As an example, it would be useless to put on wheels for a lead of 10 in. when a lead of 1·26 in. only is required. Choose a lead of, say, 1·302 in. (wheels 28–86–40–100), so that the 90° range is spread over 1·302 in. instead of over 10 in. The desired lead

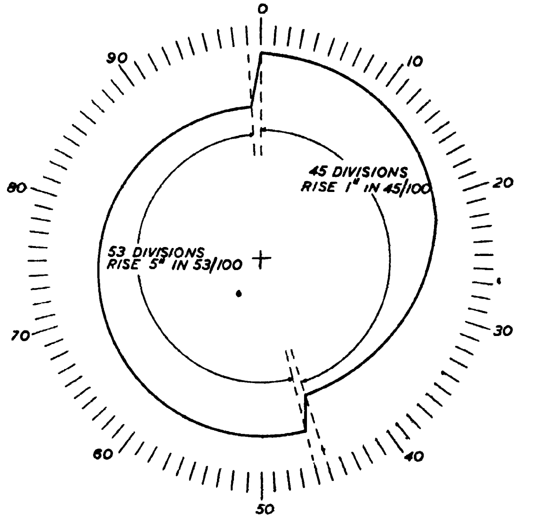

FIG. 43.—CAM LAYOUT
Showing two rises of different dimensions.

will then be read in quarter degrees instead of seconds. The reason will soon become apparent to the operator.

Setting Out the Cam Design

For ease in cutting cams it is necessary to mark out the desired cam within a circle divided into hundredths. A 360° circle can be used, but it entails better draughtsmanship and longer time; also the hundred-circle has become regular practice. Fig. 42 shows a cam with a rise of 1·25 in. in $\frac{66}{100}$ of the circle. For the purpose of this example the concentric part of the cam can be ignored, as it is produced by simply revolving the head without traversing the table. Also, the portion from 97 to zero is filed to shape when the machining is finished.

The operator must first find the true lead for the whole circle, then the sine of the true and required leads, convert the sine into degrees, the answer being the angle at which to set the head. The cosine of the same answer is the angle at which to set the attachment.

Examples

Cam to have a rise of 1·25 in. in $\frac{66}{100}$ (Fig. 42). Find true or actual lead of whole circle:

$$\frac{\text{Circle} \times \text{required lead}}{\text{Portion of circle to be cut}} = \frac{100 \times 1{\cdot}25}{66} = \frac{125}{66} = 1{\cdot}8939 \text{ in.}$$

Therefore the actual lead is 1·8939 in.

As already stated, choose a lead near the one required, say 2 in., then proceed as follows:

$\frac{\text{Required lead}}{\text{Actual lead}} = \frac{1{\cdot}8939}{2} = 0{\cdot}94695$ in. Turning to a table of sines and cosines, the nearest figure is 0·94693, the value of which is

$$0{\cdot}94693\begin{cases}\text{sine } 71^\circ\ 15', \text{ to which the head must be set.}\\ \text{cosine } 18^\circ\ 45', \text{ to which the attachment must be set.}\end{cases}$$

Fig. 43 shows another cam with two different rises, i.e. 1 in. in $\frac{45}{100}$ and $\frac{1}{2}$ in. in $\frac{53}{100}$.

Example for first portion of cam:

$$\frac{100 \times 1}{45} = \frac{100}{45} = \text{a required lead of } 2{\cdot}222 \text{ in.}$$

Wheels 24–40–24–72 give a lead of 2·222 in.; therefore set both head and attachment vertically as shown in Fig. 43, *B*, and commence cutting from point desired.

Example for second portion of cam:

$$\frac{100 \times 0{\cdot}5}{53} = \frac{50}{53} = 0{\cdot}94149 \text{ in., the required lead.}$$

The machine is already set for a lead of 2·222 in.; therefore, again the procedure is:

$$\frac{\text{Required lead}}{\text{Actual lead}} = \frac{0{\cdot}94149}{2{\cdot}222} = 0{\cdot}43271 \text{ in.}$$ The nearest figure in the trigonometrical tables is 0·42367, which is the sine of 25° 4′, at which to set the head, and the cosine of the same answer is 64° 56′, at which to set the attachment.

Where much material has to be removed, it is economical to drill the work to a rough outline and break away the portions not wanted.

Whenever possible the work should be set up so that the end mill will cut on the lower side of the blank, as this brings the mill and table nearer together and makes for greater rigidity. Chips are also prevented from accumulating, enabling the operator to see more clearly any lines that may be laid out on the cam.

When the lead of the machine is over 2 in., the automatic feed can be used, but when the feed is less than 2 in., the work should be fed by hand by aid of the crank.

To set out cams quickly a piece of sheet celluloid with a circle divided into 100 parts at which small holes are drilled is an expedient. Place the celluloid on the paper, and at the sections of the circle desired place the point of the pencil through the hole, or holes, then, on removing the celluloid, a line or lines can be drawn to the centre, giving the exact sector desired.

D. J. S.

SPUR GEARING

THE following notes outline the principles on which the various types of gear teeth are designed, and also deal with the simpler methods of cutting spur and straight-toothed bevel gearing. Two wheels in frictional contact impart, one to the other, the same peripheral speed, but when under load, there is a tendency to "slip."

To overcome this, the tooth wheel was evolved and eventually developed in a form so as to impart exactly the same motion to the second wheel as that produced in the first.

The Requirements of Gearing

The teeth must not only keep the number of revolutions correct, but must give a perfectly even and smooth motion from point to point and from tooth to tooth. Fig. 1 shows the imperative rule with all gearwheel teeth for producing a definitely even drive. In order that the teeth of one wheel shall give the same motion to the other, the condition is that a line drawn through from the point *O*, where the two wheels touch each other, and through the point where the tooth curves touch, shall be at right angles to both teeth curves at this point, whatever the position of the gear teeth. In our example the two teeth touch at *H*. If the curves are of the correct shape, a line *M–N* drawn through *H* and *O* will be at right angles to both curves at point *H*. This is the law of tooth curves. It is of no consequence what the shape of the teeth is, so far as their correct action is concerned, if this point holds true for every successive point where the teeth come into contact.

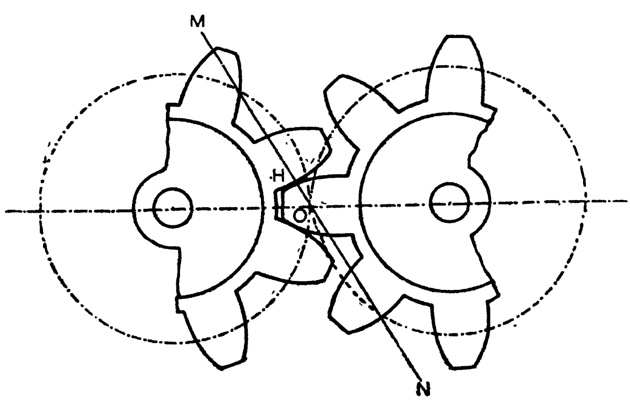

FIG. 1.—RELATION OF TEETH TO REVOLVING DISCS
The angle of pressure must be at right angles to the teeth.

Pitch Circle

The imaginary friction wheels in Fig. 1 are known as *pitch cylinders*, and in the calculation of gearing are referred to as *pitch lines*. In practical

tooth designing the pitch line generally falls midway between the tops and bottoms of the teeth, but not quite. The departure of the pitch line from the actual centre is due to clearance only. The line is also referred to as the *pitch diameter*, and is not to be confused with diametrical pitch, which will be considered later.

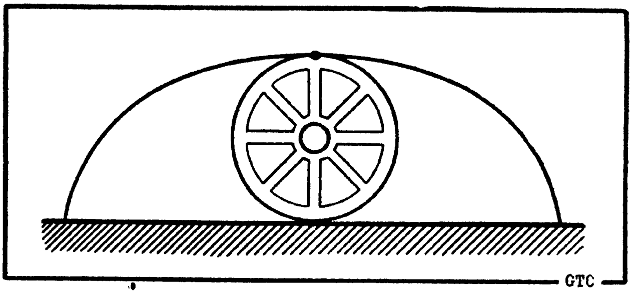

FIG. 2.—CYCLOIDAL CURVE MADE BY PATH OF POINT ON RIM OF TRUNDLED WHEEL

Cycloidal System of Gear Teeth

If a wheel is trundled along the ground, a mark made on the rim will produce a curve equal to the movement of the mark from the point where it leaves the ground until it again touches the ground. This curve is called a cycloid, and is illustrated in Fig. 2. If this wheel were rolled around another wheel, the

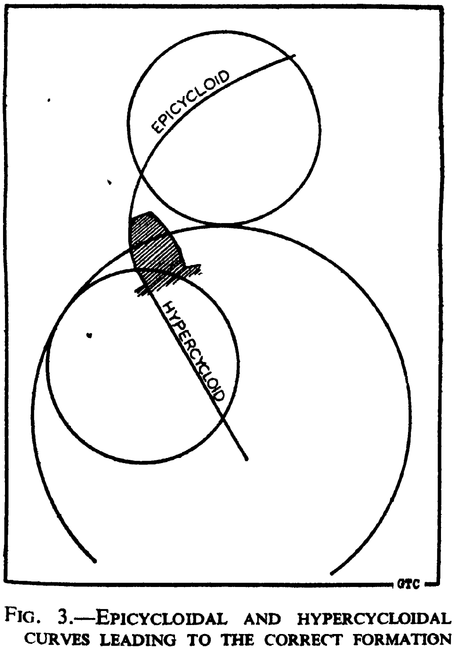

FIG. 3.—EPICYCLOIDAL AND HYPERCYCLOIDAL CURVES LEADING TO THE CORRECT FORMATION OF CYCLOIDAL TEETH

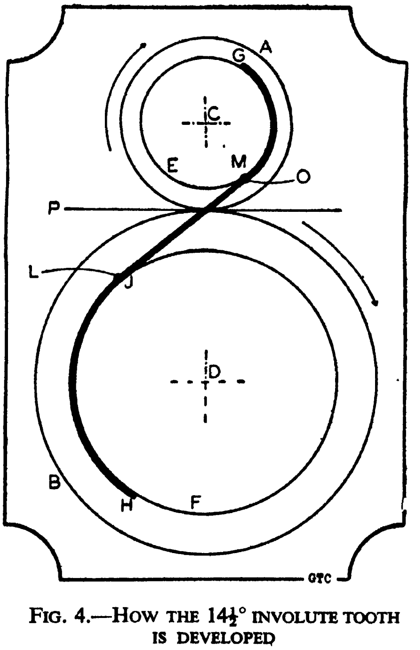

FIG. 4.—HOW THE $14\frac{1}{2}°$ INVOLUTE TOOTH IS DEVELOPED

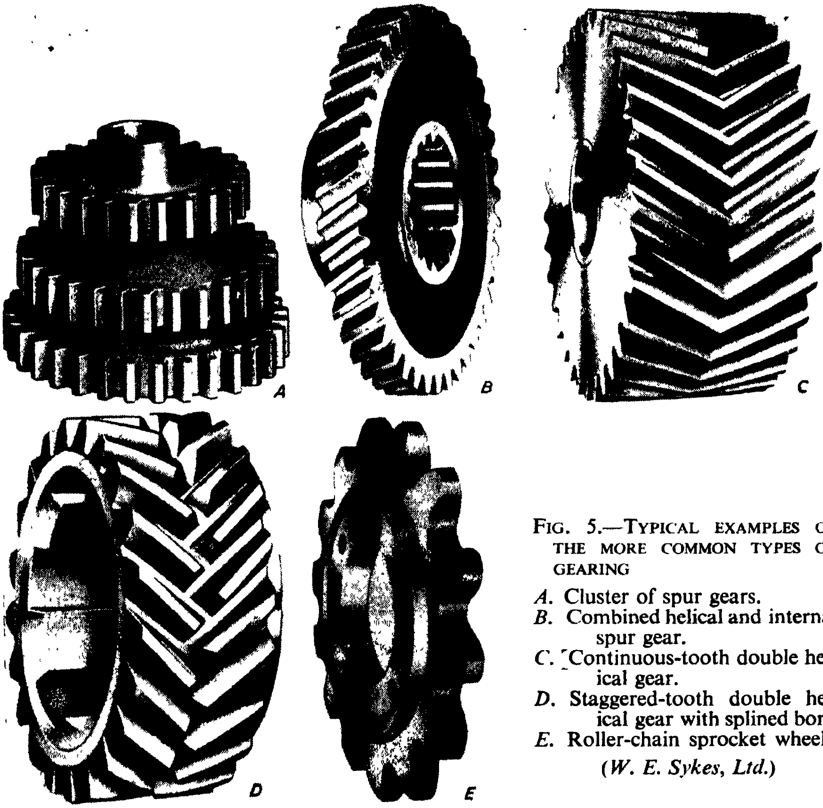

FIG. 5.—TYPICAL EXAMPLES OF THE MORE COMMON TYPES OF GEARING

A. Cluster of spur gears.
B. Combined helical and internal spur gear.
C. Continuous-tooth double helical gear.
D. Staggered-tooth double helical gear with splined bore.
E. Roller-chain sprocket wheel.

(*W. E. Sykes, Ltd.*)

curve would be an epicycloid. Should the wheel be rolled around the inside of another wheel (hoop), the curve would be a hypercycloid. The method of obtaining tooth curves on this principle is shown in Fig. 3.

The Involute System of Gear Teeth

The involute system is by far the most common, and has, no doubt, become so on account of manufacturing costs. Fig. 4 shows the principle on which the tooth is formed. *A* and *B* are two wheels with centres at *C* and *D*. These discs form the pitch circles. On *A* and *B* are smaller discs *E* and *F* fastened to the larger discs. The smaller discs are what are called base circles, and are drawn at a distance of about one-sixtieth the pitch diameter from the pitch circle. If the disc *A* is half the size of *B*, then the disc *E* must also be half the size of *F*. It is not necessary for the ratio to be one-half, but any diameter suitable for the example. A cord is stretched from *G* to *H*. If a pencil be held on the cord at *J* and the discs revolved, the pencil will make a mark like *L*. Similarly, if a pencil

be held at the cord at M, it will make a mark like O. The marks L and O will form true involute curves. The wheels will be turned in the directions of the arrows. The line P is drawn at right angles to the centre line of the two discs. The resulting angle between the centre line and the cord will be $14\frac{1}{2}°$, and is called the angle of obliquity. In some cases a 20° angle is used, especially in motor-car differential planet wheels, but the $14\frac{1}{2}°$ tooth is almost universal, and will therefore be dealt with as an explanation of gearings.

Comparison of Involute and Cycloidal Teeth

The involute tooth has the involute curve from the points A to B (Fig. 6) on the base circle. B to C, the bottom of the tooth, is a straight radial line. One difficulty with the involute system is that, with the standard length of tooth, the point A will interfere when running with pinions having a small number of teeth. To avoid this the point is rounded off somewhat below the involute curve. It should be noted that the wheel will run correctly, even if the distance between the centres of the gears is not quite correct. Fig. 1 explains the situation. The involute rack tooth has straight sides at an angle of $14\frac{1}{2}°$, but with the points slightly rounded off.

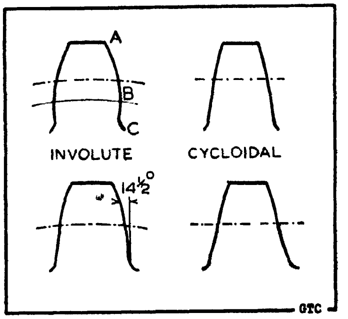

FIG. 6.—DIFFERENCE BETWEEN INVOLUTE AND CYCLOIDAL TEETH

Cycloidal teeth have two distinct curves above and below the pitch line, and in the rack the two curves are exactly alike, except that they are reversed. Whatever the system used, it is imperative that all the wheels of any given pitch should be capable of running together. With the involute system all the gears must have the same angle of obliquity, and with the cycloidal system the same size rolling circle must be employed for all sizes. The circle generally chosen is one having half the diameter of a twelve-tooth pinion, which makes the flanks of the pinion radial. The use of a larger circle means that the flank of the tooth would be curved and the curve would be inside the radial, resulting in a weak tooth.

A point in favour of the epicycloidal tooth is its freedom from interference of the opposing tooth, but this is modified from the fact that the pitch circles must absolutely touch. From the mechanic's point of view it means that his centres must be dead true. This does not apply to involute gears.

An objection to the involute system is that greater thrust is imposed on the bearings of the gears. It is true that the thrust is greater than with the cycloidal system, but the angle is constant, although it is true that the line of action is at an angle to the direction of motion. With the epicycloidal system the line of action is at right angles to a line connecting the centres of the two gears, when the two teeth are in contact on the line of centres; but the direction of this

thrusting action is variable, so that when the teeth are coming into contact with one another the pressure has an obliquity fully as great as, and often greater than, that present in standard involute gears.

Pressure Angles

Whilst the 14½° pressure-angle tooth is the most common with involute gearing, there are quite a few made with a pressure angle of 20°. This angle makes the tooth broader at the base and correspondingly narrower at the top. The strength is thus very much increased. This tooth is used in the U.S.A. on machine tools.

Rules applied to Gear Sizing, etc.

Diameter, when applied to gears, is always understood to mean the pitch diameter.

Diametrical pitch is the number of teeth to each inch of the pitch diameter. Example: If a gear has 40 teeth and the pitch diameter is 4 in., there are 10 teeth to each inch of the pitch diameter; therefore the diametrical pitch is 10. In other words, the gear is 10 diametrical pitch.

Diametrical Pitch Required.—The circular pitch is given; therefore divide 3·1416 by the circular pitch. Example: If the circular pitch is 2 in., divide 3·1416 by 2, and the answer is 1·5708, the diametrical pitch.

Diametrical Pitch Required.—The number of teeth and the outside diameter given. Add 2 to the number of teeth and divide by the outside diameter. Example: If the number of teeth is 40 and the outside diameter is 10½ in., add 2 to the number of teeth, making 42, and divide by 10½. The answer is 4, which is the diametrical pitch.

Circular pitch is the distance from the centre of one tooth to the centre of the next tooth measured on the pitch line. Example: If the distance from the centre of one tooth to the centre of the next tooth is ½ in., the gear is ½-in. circular pitch.

Circular Pitch Required.—With the diametrical pitch given, divide 3·1416 by the diametrical pitch. Example: If the diametrical pitch is 4 (found from previous rule), divide 3·1416 by 4 and the answer is 0·7854 in., which is the circular pitch.

Number of Teeth Required.—With the pitch diameter and the diametrical pitch given, multiply the pitch diameter by the diametrical pitch. Example: If the diameter of the pitch circle is 10 in. and the DP is 4, multiply by 4, and the answer will be the number of teeth, viz. 40. (Diametrical pitch is generally known as DP and the pitch diameter as the PD.)

Number of Teeth Required.—The outside diameter and the DP are given. Multiply the outside diameter by the DP and subtract 2. Example: The outside diameter is 10½ in. and the DP is 4; therefore multiply 10½ by 4 and deduct 2 from the answer—42 less 2 is 40, the number of teeth.

Pitch Diameter Required.—The number of teeth and the DP are given. Divide the number of teeth by the DP. Example: If the number of teeth is 40 and the

TABLE I.—RULES AND FORMULÆ FOR GEAR-TEETH CALCULATION

Query	*Symbol*	*Rule*	*Formula*
Diametrical Pitch	P	Divide 3·1416 by circular pitch.	$P = \frac{3{\cdot}1416}{P'}$
Diametrical Pitch	P	Divide number of teeth by pitch diameter.	$P = \frac{N}{D}$
Circular pitch	P'	Divide 3·1416 by diametrical pitch.	$P' = \frac{3{\cdot}1416}{P}$
Circular pitch	P'	Multiply pitch diameter by 3·1416 and divide by number of teeth.	$P' = \frac{3{\cdot}1416 \times D}{N}$
Pitch diameter	D	Divide number of teeth by diametrical pitch.	$D = \frac{N}{P}$
Pitch diameter	D	Multiply number of teeth by circular pitch and divide the product by 3·1416.	$D = \frac{N \times P'}{3{\cdot}1416}$
Pitch diameter	D	Subtract twice the addendum from the outside diameter.	$D = O - (2 \times S)$
Outside diameter	O	Add 2 to the number of teeth and divide the result by the diametrical pitch.	$O = \frac{N + 2}{P}$
Outside diameter	O	Multiply the sum of the number of teeth plus 2 by the circular pitch and divide the product by 3·1416.	$O = \frac{(N + 2) \times P'}{3{\cdot}1416}$
Outside diameter	O	Add twice the addendum to the pitch diameter.	$O = D + (2 \times S)$
Centre distance	C	Add the number of teeth in both gears and divide the sum by twice the diametrical pitch.	$C = \frac{Gear + Gear}{2 \times P}$
Centre distance	C	Multiply the sum of the number in both gears by the circular pitch and divide the product 6·2832.	$C = \frac{(Gear + Gear) \times P'}{6{\cdot}2832}$
Addendum	S	Divide 1 by the diametrical pitch.	$S = \frac{1}{P}$
Addendum	S	Divide circular pitch by 3·1416.	$S = \frac{P'}{3{\cdot}1416}$
Clearance	F	Divide 0·157 by the diametrical pitch.	$F = \frac{0{\cdot}157}{P}$
Clearance	F	Divide circular pitch by 20.	$F = \frac{P'}{20}$
Whole depth of tooth	W	Divide 2·157 by diametrical pitch.	$W = \frac{2{\cdot}157}{P}$
Whole depth of tooth	W	Divide 1·5708 by diametrical pitch.	$W = \frac{1{\cdot}5708}{P}$
Tooth thickness	t''	Divide circular pitch by 2.	$t'' = \frac{P'}{2}$
Tooth thickness	t''	Divide 1·5708 by diametrical pitch.	$t'' = \frac{1{\cdot}5708}{P}$
Number of teeth	N	Multiply pitch diameter by diametrical pitch.	$N = P \times D$
Number of teeth	N	Multiply pitch diameter by 3·1416 and divide the product by the circular pitch.	$N = \frac{3{\cdot}1416 \times D}{P'}$

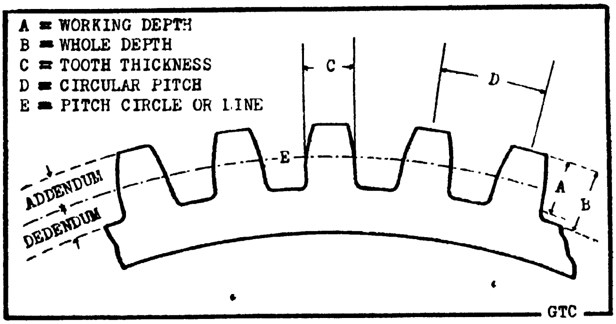

FIG. 7.—PARTS OF SPUR GEAR

DP is 4, divide 40 by 4 and the answer is 10. Expressed in inches, this is the pitch diameter (PD).

Outside diameter is the size of the gear blank required. With the number of teeth and the DP given, add 2 to the number of teeth and divide by the DP. Example: If the number of teeth is 40 and the DP is 4, add 2 to the 40, making 42, and divide by 4. The quotient, 10½, is the outside diameter of the gear or blank.

Thickness of Tooth at Pitch Line Required.—Divide the circular pitch by 2, or 1·75 by the DP. Example: If the circular pitch is 1·047 in. or the DP is 3, divide 1·047 by 2 (or 1·57 by 3) and the answer is 0·523 in., the thickness of the tooth.

Whole Depth of Tooth Required.—Divide 2·157 by the DP. Example: If the DP of a gear is 6, the whole depth is 2·157 divided by 6, which equals 0·3595 in. Whole depth of tooth is 0·6866 of the circular pitch.

Distance between Centres of Two Gears Required.—Add the number of all the teeth together and divide one-half by the sum of the DP. Example: If the two gears have 50 and 30 teeth respectively and are 5 pitch, then add the 50 to 30, making 80, and divide by 2. The quotient is 40. Divide 40 by 5 (the DP) and the answer is 8 in. between centres.

Module System of Gearing

This system is used on the European continent, and is based upon the metric system. Such wheels will be found on imported machinery and motor-cars. The diametrical pitch is not used, but the dimensions of the teeth are expressed by reference to the module of the gear, the module being equal to the pitch diameter in millimetres divided by the number of teeth in the gear. Example: If the pitch diameter of the gearwheel is 60 millimetres and the number of teeth is 20, then 60 divided by 20 is 3, which is the module of the gear.

Module of Gear Required.—Outside diameter in millimetres divided by the number of teeth plus 2.

Diametrical Pitch Required.—Number of teeth plus 2 divided by the outside diameter in millimetres.

The module is also equal to the circular pitch in millimetres divided by 3·1416.

TABLE II.—DATA FOR MODULE TEETH

Module	*D.P.*	*Addendum*		*Chordal Thickness of Tooth on Pitch Line*		*Whole Depth of Tooth*	
		mm.	*in.*	*mm.*	*in.*	*mm.*	*in.*
0·50	50·800	0·50	0·0197	0·785	0·0309	1·078	0·0425
0·75	33·867	0·75	0·0295	1·178	0·0464	1·617	0·0637
1·00	25·400	1·00	0·0394	1·571	0·0618	2·157	0·0849
1·25	20·320	1·25	0·0492	1·963	0·0773	2·696	0·1062
1·50	16·933	1·50	0·0591	2·356	0·0928	3·235	0·1274
1·75	14·514	1·75	0·0689	2·748	0·1082	3·774	0·1485
2·00	12·700	2·00	0·0787	3·142	0·1237	4·314	0·1698
2·25	11·288	2·25	0·0885	3·534	0·1391	4·853	0·1911
2·50	10·160	2·50	0·0984	3·927	0·1545	5·392	0·2123
2·75	9·236	2·75	0·1082	4·319	0·1700	5·931	0·2335
3·00	8·466	3·00	0·1181	4·712	0·1855	6·471	0·2547
3·50	7·257	3·50	0·1378	5·497	0·2164	7·549	0·2972
4·00	6·350	4·00	0·1575	6·283	0·2473	8·628	0·3397
4·50	5·644	4·50	0·1772	7·068	0·2783	9·706	0·3821
5·00	5·080	5·00	0·1969	7·854	0·3092	10·785	0·4246
5·50	4·618	5·50	0·2166	8·639	0·3401	11·863	0·4671
6·00	4·233	6·00	0·2362	9·424	0·3710	12·942	0·5095
7·00	3·628	7·00	0·2756	10·995	0·4328	15·099	0·5944
8·00	3·175	8·00	0·3150	12·566	0·4947	17·256	0·6794
9·00	2·822	9·00	0·3543	14·137	0·5565	19·413	0·7643
10·00	2·540	10·00	0·3937	15·708	0·6184	21·570	0·8492
11·00	2·309	11·00	0·4331	17·278	0·6803	23·727	0·9341
12·00	2·117	12·00	0·4724	18·849	0·7421	25·884	1·0190
14·00	1·814	14·00	0·5512	21·991	0·8656	30·198	1·1888
16·00	1·587	16·00	0·6299	25·132	0·9894	34·512	1·3588
18·00	1·411	18·00	0·7087	28·274	1·1131	38·826	1·5286
20·00	1·270	20·00	0·7874	31·416	1·2369	43·140	1·6984
24·00	1·058	24·00	0·9449	37·699	1·4841	51·768	2·0381

CUTTING SPUR GEARS

Cutting involute gears with a milling cutter made to the shape of the required tooth is a method employed extensively for small-quantity production. For mass production the expense of special gear-cutting machines is warranted by the large output.

Cutting with Formed Cutters

The cutting of involute gears presents no real difficulty on account of the ease with which cutters can be obtained. The Brown & Sharpe Manufacturing Co., of the U.S.A., make cutters that will deal with all pitches ranging from 12 teeth per wheel to a straight rack. In this country Messrs. Buck & Hickman, Ltd., the well-known tool makers, manufacture a similar range of cutters.

The design of these cutters does away with a multitude of gear cutters that would, in the ordinary sense, be required for such work. The cutter range is as follows:

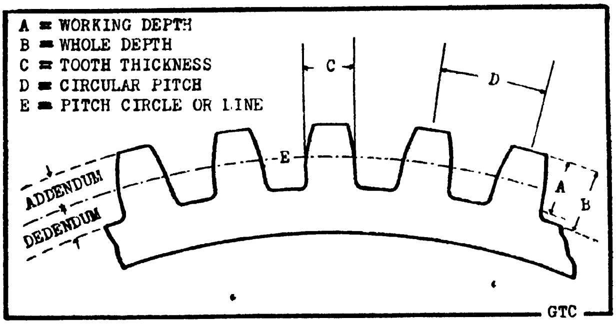

FIG. 7.—PARTS OF SPUR GEAR

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Distance between Centres of Two Gears Required.—Add the number of all the teeth together and divide one-half by the sum of the DP. Example: If the two gears have 50 and 30 teeth respectively and are 5 pitch, then add the 50 to 30, making 80, and divide by 2. The quotient is 40. Divide 40 by 5 (the DP) and the answer is 8 in. between centres.

Module System of Gearing

This system is used on the European continent, and is based upon the metric system. Such wheels will be found on imported machinery and motor-cars. The diametrical pitch is not used, but the dimensions of the teeth are expressed by reference to the module of the gear, the module being equal to the pitch diameter in millimetres divided by the number of teeth in the gear. Example: If the pitch diameter of the gearwheel is 60 millimetres and the number of teeth is 20, then 60 divided by 20 is 3, which is the module of the gear.

Module of Gear Required.—Outside diameter in millimetres divided by the number of teeth plus 2.

Diametrical Pitch Required.—Number of teeth plus 2 divided by the outside diameter in millimetres.

The module is also equal to the circular pitch in millimetres divided by 3·1416.

Sharpening Cutters

For economy alone cutters must be kept well sharpened. Sharp cutters permit faster working, consume less power, produce better surfaces, and wear much longer. Use a bevel or concave grinding wheel of medium grain and soft grade, just hard enough to prevent the grit from flying about. Keep the wheel clean, as a glazed wheel draws the temper of the cutter; also keep the corner sharp to give a true surface to the entire length of the cutter tooth. In grinding the cutter, the face of every tooth must be kept radial, and all must be the same height. When not ground radially, they are either "hooking," as shown at *C* in Fig. 10, which cuts too deep, or "dragging" as at *B*, which cuts too shallow. Besides this, all cutter teeth are relieved so that the cutting outline of the tooth remains correct only when ground radially. Teeth ground as at *A*, *B*, and *C* will cut gear teeth the wrong shape. Be careful to keep each tooth face square with the sides of the cutter, avoiding mistakes like *A*. If some of the teeth are longer than others, the long teeth will do all the work. The unlettered line on the sketch is the correct way to grind a cutter.

Setting the Cutter

It is essential that the cutter is exactly central with the axis of the gear blank, especially when the gear is to run fast, otherwise the gear will be cut "off-centre" and will run more noisily in one direction than in the other. The following is the correct method of setting for very accurate teeth. Set the cutter or the table above the mandrel as nearly as possible in position; fasten the gear blank, or preferably an odd blank of about the same size as the gear to be cut, on the mandrel, and lock it in position between centres. Take a single cut and then remove the blank from the mandrel, turn it end for end, and replace it on the machine. Permit the mandrel to remain loose between the centres, and see if the cutter will pass through the groove already cut without removing any stock from either side of the groove. If the cutter is not exactly central, the stock will be cut from the upper part on one side of the groove and from the lower part on the other side of the groove. If the cutter does not pass clean through the groove, adjustment must be made to either cutter or table.

A quicker method, not so accurate, but accurate enough for slow-running gears, is to position the cutter and blank as near as possible with the aid of the eye. Start the machine and raise the blank until it is just scraped by the cutter. Adjust table so that the cutter moves at right angles to the intended tooth groove, leaving a mark on the top of the blank. The centre of this mark will be the centre of the blank—near enough for ordinary purposes. The operator should always have a glass-stoppered bottle of copper sulphate dissolved in very slightly acidical water. Paint a little on the bright blank and thus copper-plate the spot. The scratch made by the cutter passing along the blank will then more readily show up.

Some gear cutters have a line on the tops of the teeth that is central with the form, and for ordinary running gears the cutter may be centralised by bringing

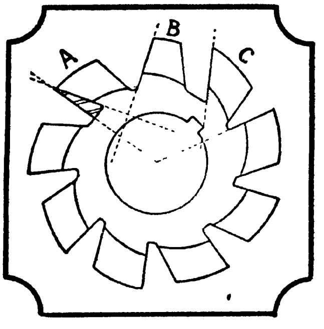

FIG. 10.—INCORRECT WAY TO GRIND BROWN & SHARPE INVOLUTE CUTTERS

this line to coincide with the centre in the head and footstock, using the latter instruction.

Measuring Blanks

Measure all blanks accurately. The importance of this cannot be over-estimated. It is impossible to cut correct-running gears from blanks that are the wrong diameter. It has been mentioned that the involute tooth does permit slight error, but if the depth of tooth is to be determined from the diameter of the blank, a too small blank will produce a tooth too thin on the pitch line and too deep. If the blank is, say, 0·003 in. too small in diameter, it means that the cutter must be set 0·0015 in. less than formula, which information is marked on the cutter itself. It is certain the amount of error allowable depends on the pitch of the gear: the heavier the gear, the greater the tolerance. Blanks that are over size must be returned to the turner to be correctly dimensioned, which is a tip to the gear-cutter operative to take nothing for granted and take a measurement himself before commencing to cut the teeth.

Securing the Blank on the Mandrel

The next important step is to see that the mandrel runs true and that the blank does not spring when it is forced or tightened. A good method of holding blanks is on milling-machine mandrels that have a taper shank which fits the indexing head. The other end is supported by the usual footstock centre. The driving carrier as used on a lathe is of no use, as it cannot be held in place on the indexing head or indexing centre. It must be remembered that the mandrel on which the blank is placed must not move from the selected position.

Setting Knee of Machine for Depth of Cut

The depth of cut is regulated by the height of the knee of the machine. To make this setting, the knee is brought up until the cutter just touches the blank. Then the blank is moved from under the cutter and the knee raised the number of thousandths of an inch required for depth of tooth. Be sure to take out any backlash before raising the knee. The formula for ascertaining the depth to be cut is to divide the constant 2·157 by the DP.

Testing the Correct Depth

To make certain that the depth of the groove cut is correct and the size of the teeth accurate, cut two grooves into the blank far enough so that the full form of a tooth is produced, and then measure the result at the pitch line for thickness and the depth of the tooth to the pitch line. The correct thickness of

spur teeth of different pitches at the pitch line is found by dividing the constant 1·57 by the DP (Fig. 11).

By cutting only part of the way across the face of the blank, the trial grooves can be quickly made and easily measured. If, on the other hand, the grooves are cut across the full width of the face, there is the liability, under some conditions, of more stock being taken from these grooves when the actual cutting is commenced and the cutter is allowed to pass through the same groove the second time, thus making these grooves too deep.

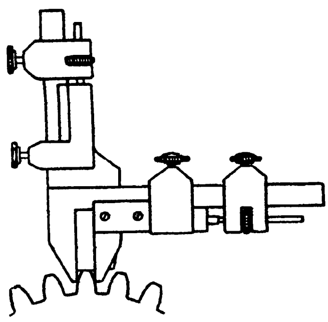

FIG. 11.—TOOTH VERNIER

Chordal Thickness of Gear Teeth

When accurate measurements of gear teeth are required, it is necessary to work to chordal figures (Fig. 12): t'' equals the thickness of the tooth, and s'' equals the distance from chord t'' to top of tooth. The fewer the number of teeth in a gear, the greater the variation. In Table III the dimensions of t'' and s'' are given for gears of 1 DP. To obtain t'' and s'' for any DP, divide the figures given in the table opposite the required number of teeth by the required DP.

Example: Find t'' and s'' for a gear of 5 DP and 23 teeth. 1·5696 divided by 5 equals 0·3139, which equals t''. Also, 1·0268 divided by 5 equals 0·2054, which equals s''.

Gear-tooth Thickness Gauge

An accurate tool for taking the measurements of gear teeth is shown in Fig. 11. It will be noted that it is on the vernier principle. The depth of grooves may be ascertained when there is an even number of teeth by cutting two grooves opposite each other on the circumference of the blank and callipering the diameter from the bottom of the grooves, then computing the depth. When the number of teeth is uneven, cut one groove and calliper the diameter from the bottom of the groove to the opposite side of the blank. In this latter case be sure the blank is of the correct diameter and runs true, otherwise the measurement will not be correct, unless allowance is made for these points.

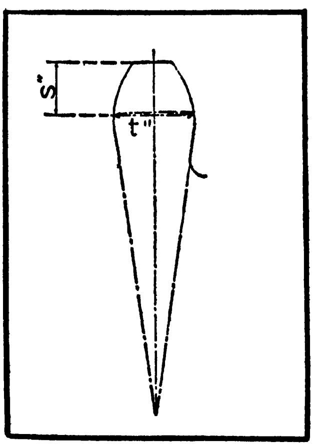

FIG. 12.—CHORDAL THICKNESS OF TEETH AND DEPTH OF TOOTH TO PITCH LINE

Caution in cutting Two or More Gears Simultaneously

If the holes in the blanks are straight, and the hubs do not project beyond the face,

TABLE III.—CHORDAL THICKNESS OF GEAR TEETH (t'') AND DISTANCE FROM CHORD TO TOP OF TOOTH (s'')

(For Gears of 1 DP)

Number of Teeth	t''	s''	*Number of Teeth*	t''	s''	*Number of Teeth*	t''	s''
6	1·5529	1·1022	**50**	1·5705	1·0123	**94**	1·5707	1·0066
7	1·5568	1·0873	**51**	1·5706	1·0121	**95**	1·5707	1·0065
8	1·5607	1·0769	**52**	1·5706	1·0119	**96**	1·5707	1·0064
9	1·5628	1·0684	**53**	1·5706	1·0117	**97**	1·5707	1·0064
10	1·5643	1·0616	**54**	1·5706	1·0114	**98**	1·5707	1·0063
11	1·5654	1·0559	**55**	1·5706	1·0112	**99**	1·5707	1·0062
12	1·5663	1·0514	**56**	1·5706	1·0110	**100**	1·5707	1·0061
13	1·5670	1·0474	**57**	1·5706	1·0108	**101**	1·5707	1·0061
14	1·5675	1·0440	**58**	1·5706	1·0106	**102**	1·5707	1·0060
15	1·5679	1·0411	**59**	1·5706	1·0105	**103**	1·5707	1·0060
16	1·5683	1·0385	**60**	1·5706	1·0102	**104**	1·5707	1·0059
17	1·5686	1·0362	**61**	1·5706	1·0101	**105**	1·5707	1·0059
18	1·5688	1·0342	**62**	1·5706	1·0100	**106**	1·5707	1·0058
19	1·5690	1·0324	**63**	1·5706	1·0098	**107**	1·5707	1·0058
20	1·5692	1·0308	**64**	1·5706	1·0097	**108**	1·5707	1·0057
21	1·5694	1·0294	**65**	1·5706	1·0095	**109**	1·5707	1·0057
22	1·5695	1·0281	**66**	1·5706	1·0094	**110**	1·5707	1·0056
23	1·5696	1·0268	**67**	1·5706	1·0092	**111**	1·5707	1·0056
24	1·5697	1·0257	**68**	1·5706	1·0091	**112**	1·5707	1·0055
25	1·5698	1·0247	**69**	1·5707	1·0090	**113**	1·5707	1·0055
26	1·5698	1·0237	**70**	1·5707	1·0088	**114**	1·5707	1·0054
27	1·5699	1·0228	**71**	1·5707	1·0087	**115**	1·5707	1·0054
28	1·5700	1·0220	**72**	1·5707	1·0086	**116**	1·5707	1·0053
29	1·5700	1·0213	**73**	1·5707	1·0085	**117**	1·5707	1·0053
30	1·5701	1·0208	**74**	1·5707	1·0084	**118**	1·5707	1·0053
31	1·5701	1·0199	**75**	1·5707	1·0083	**119**	1·5707	1·0052
32	1·5702	1·0193	**76**	1·5707	1·0081	**120**	1·5707	1·0052
33	1·5702	1·0187	**77**	1·5707	1·0080	**121**	1·5707	1·0051
34	1·5702	1·0181	**78**	1·5707	1·0079	**122**	1·5707	1·0051
35	1·5702	1·0176	**79**	1·5707	1·0078	**123**	1·5707	1·0050
36	1·5703	1·0171	**80**	1·5807	1·0077	**124**	1·5707	1·0050
37	1·5703	1·0167	**81**	1·5707	1·0076	**125**	1·5707	1·0049
38	1·5703	1·0162	**82**	1·5707	1·0075	**126**	1·5707	1·0049
39	1·5704	1·0158	**83**	1·5707	1·0074	**127**	1·5707	1·0049
40	1·5704	1·0154	**84**	1·5707	1·0074	**128**	1·5707	1·0048
41	1·5704	1·0150	**85**	1·5707	1·0073	**129**	1·5707	1·0048
42	1·5704	1·0147	**86**	1·5707	1·0072	**130**	1·5707	1·0047
43	1·5705	1·0143	**87**	1·5707	1·0071	**131**	1·5708	1·0047
44	1·5705	1·0140	**88**	1·5707	1·0070	**132**	1·5708	1·0047
45	1·5705	1·0137	**89**	1·5707	1·0069	**133**	1·5708	1·0047
46	1·5705	1·0134	**90**	1·5707	1·0068	**134**	1·5708	1·0046
47	1·5705	1·0131	**91**	1·5707	1·0068	**135**	1·5708	1·0046
48	1·5705	1·0129	**92**	1·5707	1·0067	**150**	1·5708	1·0045
49	1·5705	1·0126	**93**	1·5707	1·0067	**250**	1·5708	1·0025

For Rack $t = 1{\cdot}5708$, $s = 1{\cdot}0000$

a number of blanks may be fastened together on a mandrel and several gears cut at a time. Care should be taken, however, if this is done, to see that the sides of the blanks are exactly parallel, otherwise, when the mandrel nut is tightened, the blanks will spring the mandrel, with the result that it will be impossible to cut accurate gears, and perhaps result in a spoiled mandrel. It is frequently the case that machined parts not needing an accurate finish are neglected; therefore great care should be taken before assembling the blanks.

Cutting Racks

A "rack" is a straight piece with teeth to mesh with a gear. It may be looked upon as a gear infinitely long with long radius. The circumference of a circle approaches a straight line as the radius increases, and when the radius is infinitely long, any finite part of the circumference is a straight line. The pitch line of a rack is merely a straight line just touching the pitch circle of a gear meshing with it. The thickness of the teeth, addendum, and depth of teeth below the pitch line are calculated the same as for a wheel. The actual milling is a simple matter. When such necessary data as the dimensions of the teeth are known, the correct cutter is selected and set to depth; the only remaining requirement then is to move the table transversely the proper distance between cuts. It should then be remembered to remove all backlash before commencing the actual cutting.

Cutting Bevel Gears with Ordinary Cutters

The teeth of bevel gears constantly change in pitch from their large to their small end, and for this reason it is impossible to cut gears whose tooth curves are theoretically correct with rotary cutters having fixed curves, such as those used for cutting ordinary gears in milling machines. The cutter employed must have a curve that will make the correct form at the large end of the tooth; hence it will leave the curve at the small end too straight. It is therefore the practice to cut the teeth as nearly correct as possible and then finish the gear teeth by hand, filing the small ends of the teeth to the correct curve.

Pitch of Bevel Gear

The pitch of a bevel gear is always considered as that of the largest end of the tooth.

Data required to cut Bevel Gears with Rotary Cutter

Pitch and number of teeth of each gear.

The whole depth of tooth spaces at both large and small ends of teeth.

The thickness of teeth at both ends.

The cutting angle, the angle to set the headstock on the milling machine, and the proper cutter, or cutters.

Scratching Depth Line on Blank

Before placing the blank on the machine, measure the length of face, angles, and outside diameter of blank, and, if all dimensions are correct, place the blank on the mandrel and fasten it securely in place; then scratch the whole depth of the space at the large end with a depth tooth gauge as shown in Fig. 13 (top left).

Selection of Cutter

The length of teeth or face on bevel gears is not ordinarily more than one-third the apex distance, *Ab* in Fig. 13, and cutters usually carried in stock are suitable for this face. If the face is longer than one-third the apex distance, special thin cutters must be made; therefore the general engineer should take care that the making of the wheel will be an economic proposition. Measure the back cone radius *ab* for the pinion. This is equal to the radius of a spur gear, the number of teeth in which would determine the cutter to use. Hence twice *ab* times the DP equals the number of teeth for which the cutter should be selected for the gear. The list of cutters on page 364 will give the suitable cutter. Example: Thus, let the cone radius *ab* be 4 in. and the diametrical pitch be 8. Twice 4 is 8, and 8×8 is 64, from which it can be seen that the cutter must be a Brown & Sharpe No. 2, as 64 is between 55 and 134, the range covered by a No. 2 cutter.

If the gears are mitres or are alike, only one cutter is needed; if one gear is larger than the other, two may be needed.

Setting the Cutter out of Centre

As the cutter cannot be any thicker than the width of space at the small end of the teeth, it is necessary to set it out of centre and rotate the blank to make the spaces of the right width at the large end of the teeth. The amount to set the cutter out of centre can be calculated with Table IV and the following formula:

$$\textit{Set-over} = \frac{Te}{2} - \frac{\textit{Factor from Table}}{P}$$

P = diametrical pitch of gear to be cut.
Te = thickness of cutter used, measured at pitch line.

Given as a rule this would read: Find the factor in the table corresponding to the number of the cutter used and to the ratio of the apex distance to width of face; divide this factor by the diametrical pitch and subtract the quotient from half of the thickness of the cutter at the pitch line.

To illustrate the use of the table in obtaining set-over, take the following example: A bevel gear of 24 teeth, 6 pitch, 30° pitch cone angle, and $1\frac{3}{4}$ in. face. These dimensions call for a No. 4 cutter and an apex distance of 4 in. In order to get the factor from the table, the ratio of apex distance with length of face must be known. This ratio is $\frac{4}{1{\cdot}25} = \frac{3{\cdot}2}{1}$, or about $\frac{3\frac{1}{4}}{1}$. The factor in the table

TABLE IV.—OBTAINING SET-OVER FOR CUTTING BEVEL GEARS

Ratio of Apex distance to width of face $= \frac{\text{Apex}}{\text{Face}}$

No. of Cutter	$\frac{3}{1}$	$\frac{3\frac{1}{4}}{1}$	$\frac{3\frac{1}{2}}{1}$	$\frac{3\frac{3}{4}}{1}$	$\frac{4}{1}$	$\frac{4\frac{1}{4}}{1}$	$\frac{4\frac{1}{2}}{1}$	$\frac{4\frac{3}{4}}{1}$	$\frac{5}{1}$	$\frac{5\frac{1}{2}}{1}$	$\frac{6}{1}$	$\frac{7}{1}$	$\frac{8}{1}$
1	0·254	0·254	0·255	0·256	0·257	0·257	0·257	0·25[illegible]	0·258	0·259	0·260	0·262	0·264
2	0·266	0·268	0·271	0·272	0·273	0·274	0·274	0·275	0·277	0·279	0·280	0·283	0·284
3	0·266	0·268	0·271	0·273	0·275	0·278	0·280	0·282	0·283	0·286	0·287	0·290	0·292
4	0·275	0·280	0·285	0·287	0·291	0·293	0·296	0·298	0·298	0·302	0·305	0·308	0·311
5	0·280	0·285	0·290	0·293	0·295	0·296	0·298	0·300	0·302	0·307	0·309	0·313	0·315
6	0·311	0·318	0·323	0·328	0·330	0·334	0·337	0·340	0·343	0·348	0·352	0·356	0·362
7	0·289	0·289	0·308	0·316	0·324	0·329	0·334	0·338	0·343	0·350	0·360	0·370	0·376
8	0·275	0·286	0·296	0·309	0·319	0·331	0·338	0·344	0·352	0·361	0·368	0·380	0·386

for this ratio with a No. 4 cutter is 0·280. Next measure the cutter at the pitch line, which equals 0·1745. This dimension will vary with different cutters, and will vary with the same cutter as it is ground away, since the formed bevel-gear cutters are commonly provided with side relief. Substituting these values in the formula, the set-over is $\frac{0·1745}{2} - \frac{0·280}{6} = 0·0406$ in.

After selecting a cutter and determining how much to set it out of centre, set the cutter central with the headstock of the universal spiral index head spindle.

Set the head to the correct cutting angle (this may be found from tables on cutting bevels or from the formulæ given on page 373).

Set the index head for the number of teeth to be cut, placing the sector on the straight row of holes that are numbered to start with (see section dealing with indexing).

Set the dial of the cross-feed screw to the zero line.

Scratch the depth of both the large and small end of the tooth to be cut in the blank.

Index and cut two or three grooves, or centre cuts, to conform to the lines in depth.

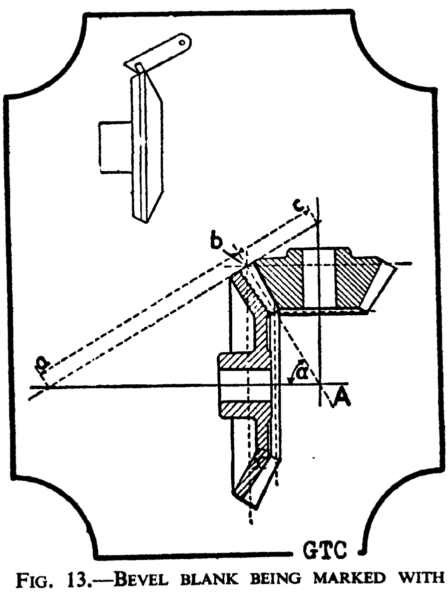

FIG. 13.—BEVEL BLANK BEING MARKED WITH GAUGE

Right-angled bevels.

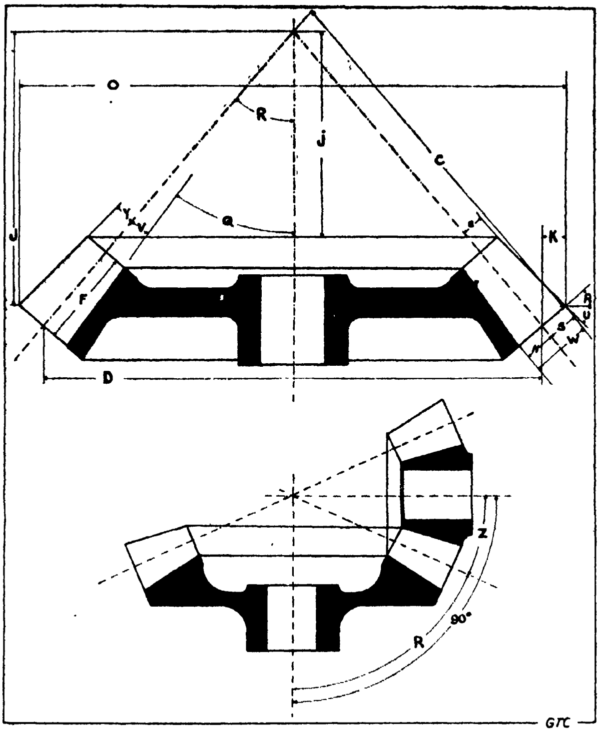

FIG. 14.—RIGHT-ANGLED BEVEL WHEELS, SHOWING PARTS

C, pitch-line radius. *D*, pitch diameter. *H*, dedendum. *J*, apex distance. *j*, apex distance at small end of tooth. *K*, angular distance. *O*, outside diameter. *Q*, cutting angle. *R*, pitch cone angle of GR. *S*, addendum. *s*, addendum at small end of tooth. *U*, face angle. *V*, dedendum angle. *W*, whole tooth depth. *Y*, addendum angle. *Z*, pitch-cone angle of pinion.

Set the cutter out of centre the trial distance, according to the formula already explained, by moving the saddle and noting the adjustment on the cross-feed screw dial. Rotate the gear in the opposite direction from that in which the table is moved off-centre (Fig. 15) until the side of the cutter nearest the centre line of the gear will cut the entire surfaces of the approaching sides of the teeth.

After making one or more cuts in accordance with this setting, move the table the same distance on the opposite side of the centre and rotate the gear in the opposite direction from that in which the table is moved until the cutter just touches the side of the tooth at the small end and cuts the entire surface of this side the same as the other.

Cut one or more spaces and measure the teeth at both large and small ends, either with the gear-tooth vernier or with gauges made from thin pieces of metal and having a slot cut to give the correct depth and width at the pitch line. If the teeth at the large end are too thick when the small end is correct, the amount to set the table over must be increased. On the other hand, if the small end is too thick when the large end is correct, the amount the table is set over is too great. In either case the settings must be changed and the cutting operations repeated,

TABLE V.—RULES AND FORMULÆ FOR THE CALCULATION OF RIGHT-ANGLED BEVEL WHEELS

Query	*Symbol*	*Rule*	*Formula*
Pitch-cone angle of pinion	Z	Divide number of teeth in pinion by the number of teeth in gear to first obtain tangent.	$\tan = \frac{\text{No. of teeth in pin}}{\text{No. of teeth in gear}}$
Pitch-cone angle of gear	R	Divide number of teeth in gear by the number of teeth in pinion to first obtain tangent.	$\tan R = \frac{\text{No. of teeth in pin}}{\text{No. of teeth in gear}}$
Pitch diameter	D	Divide the number of teeth by the diametrical pitch, or multiply the number of teeth by the circular pitch.	$D = \frac{N}{P} = \frac{N \times P'}{Pi}$
Outside diameter	O	Add twice the angular dedendum to the pitch diameter.	$O = D + (2 \times K)$
Apex distance	J	Multiply the radius of the outside diameter by the tangent of the face angle.	$J = \frac{O}{2} \times \tan U$
Apex distance at small end of tooth	j	Subtract the width of face from the pitch-cone radius, then divide the remainder by the pitch-cone radius and multiply by the apex distance.	$j = J \times \frac{C - F}{C}$
Number of teeth from which to select cutter	N'	Divide the number of teeth by the cosine of the pitch-cone angle.	$N' = \frac{N}{\cos R}$
Addendum	S	Divide 1 by the diametrical pitch or multiply the circular pitch by 0·318.	$S = \frac{1{\cdot}0}{P}$
Dedendum	H	Divide 1·157 by the diametrical pitch or multiply the circular pitch by 0·368.	$H = \frac{1{\cdot}157}{P}$
Addendum angle	Y	Divide the addendum by the pitch-cone radius and obtain first the tangent.	$\tan Y = \frac{S}{C}$
Dedendum angle	V	Divide the dedendum by the pitch-cone radius to first get the tangent.	$\tan V = \frac{H}{C}$
Angular dedendum	K	Multiply the addendum by the cosine of the pitch-cone angle.	$K = S \times \cos R$
Addendum of small end of tooth	s	Subtract the width of face from cone radius, divide the remainder by the pitch-cone radius, and multiply by the addendum.	$s = S \times \frac{C - F}{C}$
Face angle	U	Subtract the sum of the pitch-cone and addendum angles from 90°.	$U = 90 - (R + U)$
Cutting angle	Q	Subtract the dedendum angle from the pitch-cone angle.	$Q = R - V$
Thickness of tooth on pitch line at small end	t	Subtract the width of face from the pitch-cone radius and divide the remainder by the pitch cone.	$t = T \times \frac{C - F}{C}$
Thickness of tooth at pitch line	T	Divide 1·571 by the diametrical pitch, or divide the circular pitch by 2.	$T = \frac{1{\cdot}571}{P} = \frac{P'}{2}$
Pitch-cone radius	C	Divide the pitch diameter by twice the sine of the pitch-cone angle.	$C = \frac{D}{2 \times \sin R}$
Whole tooth depth	W	Divide 2·157 by the diametrical pitch or multiply the circular pitch by 0·687	$W = \frac{2{\cdot}157}{P}$

Note.—**The addendum, dedendum, whole tooth depth, thickness of tooth at pitch line, pitch-cone radius, thickness of tooth on pitch line at small end, addendum angle, and dedendum angle are the same for both bevel wheels.**

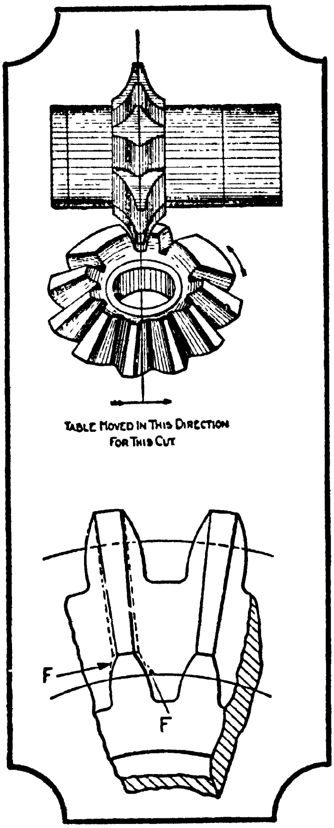

FIG. 15.—METHOD OF SETTING OVER BLANK TO OBTAIN CORRECT FORMATION

F–F shows part of tooth to be removed by file. Note the removal does not touch the pitch line. This is most important if the correct tooth formation is to be observed.

remembering that the blank must be rotated and the table moved the same amount each side of centre, otherwise the teeth will not be central. It is well to bear in mind that too much out of centre leaves the small end proportionately too thick, and too little out of centre leaves the small end too thin.

The adjustment of the cutter and the rotating of the blank are shown in Fig. 15, which shows the setting so that the right side of the cutter will trim the left side of the tooth and widen the large end of the space. The table has been moved to the right and the blank brought into the position shown, by rotating in the direction of the arrow. The first out-of-centre cut was taken when the cutter was set on the other side of the centre.

After determining the proper amount to set the cutter, the teeth can be finished without making a central cut by cutting round the blank with the cutter set out of centre, first on one side and then on the other.

Precautions against too Thin Teeth

To prevent the teeth being too thin at either end it is important, after cutting once round the blank with the cutter out of centre, to give careful attention to the rotative adjustment of the gear blank when setting the cutter for trimming the opposite sides of the teeth. If, by measurement, both ends are a little too thick, but proportionately right, rotate the gear blank and make trial cuts until one tooth is of the correct thickness at ends. The cutting can then be continued until the gear is finished. Teeth of incorrect thickness may be more objectionable than a slight variation in depth. The instructions given may seem somewhat complicated, but in actual practice the process is soon acquired and is far more simple than it appears in print.

Finishing off the Shape of the Teeth

The finished spaces, or teeth, as already mentioned, are the correct form at the larger ends, and the teeth are of the correct thickness their entire length,

but the tops of the teeth at the small ends are not rounded off sufficiently. It is therefore generally necessary to file the faces of the teeth slightly above the pitch line at the small ends as *F–F* in Fig. 15. In filing the teeth, they should not be reduced in thickness at or below the pitch line.

When cutting cast-iron gears coarser than 5 DP, it is best to make one central cut entirely around the blank before attempting to find the correct setting of the cutter or rotation of the blank for correct thickness of teeth; and it is generally advantageous to take a central cut on nearly all bevel wheels of steel.

GEAR-PRODUCTION METHODS

GEARS were first produced by casting them in the foundry, a method which is still employed to a limited extent for larger gears that are not required to run at very high speeds. Cast gears, however, are not sufficiently accurate for most modern applications, where quiet and smooth running at very high speeds are generally essential. Sometimes, to reduce cutting times and costs, large-pitch gears are cast with oversize teeth and then finished on a machine, thus avoiding the need for lengthy "roughing" operations.

Small gears for certain types of light mechanism may be produced to very close limits of accuracy by the die-casting processes, but these are generally not suitable for large work or heavy power transmission, because of the fact that they can only be produced in zinc-base alloys, aluminium alloys, or one of the other soft die-casting materials.

SPUR GEARS

The spur gear is the most simple of all the types of gear. Apart from casting, the oldest method of cutting spur gears, still employed in small shops, is on an ordinary plain or universal horizontal milling machine equipped with a dividing head. Mounted on the arbor is a cutter chosen to suit the pitch and number of teeth, this information being clearly marked on the side. When setting up care must be taken to ensure that the gear blank "runs true," otherwise the teeth on one side will be deeper than on the other. This is done by rotating the blank with a dial indicator resting first on the periphery and then on the side. Care must also be taken to set the cutter absolutely central with the blank, or misshapen teeth will result.

The size of gear which can be cut by this method is limited by the capacity of the machine, and usually is not very large. The operation is comparatively slow, and needs attention each time the blank is indexed to the next tooth.

Automatic Gear Cutters

This resulted in the development of automatic gear cutters. In this type of machine the blanks are mounted on an arbor supported at one end in a large indexing wheel, and at the other end by a centre or other form of outboard support. By means of change gears the wheel may be set to index the work to suit the number of teeth to be cut in the blank. Moving on slides underneath the blank is a rotating cutter. This traverses across the face of the blank at a pre-set cutting feed, and at the end of the stroke returns to a fast speed. When it is clear from the blank it encounters a stop which actuates mechanism,

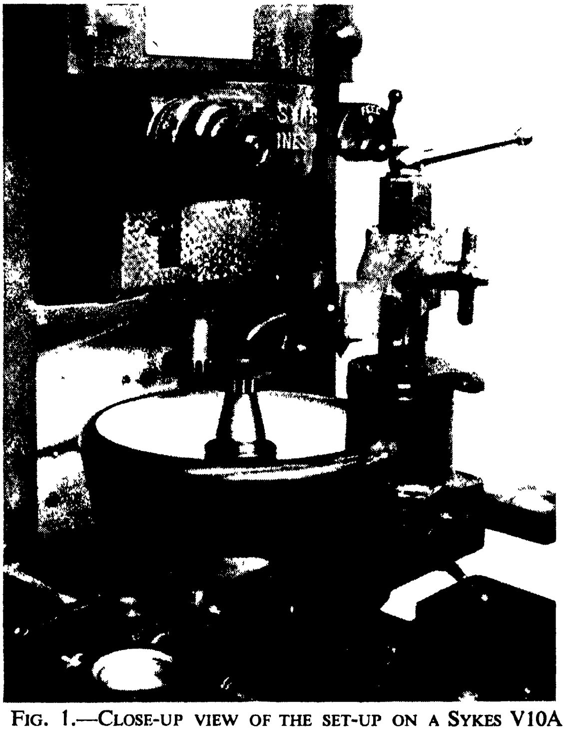

FIG. 1.—CLOSE-UP VIEW OF THE SET-UP ON A SYKES V10A MACHINE WHEN CUTTING A SPUR GEAR

causing the work automatically to index to the next tooth position. The cutter then commences to feed again into the blank, this cycle continuing automatically and without attention until all the teeth are cut. If the quantities are sufficiently large and the dimensions permit, a number of blanks may be mounted on the arbor at each setting. As a rule, this type of machine is reserved for larger gears, ranging upwards from approximately 1 ft. in diameter.

Gear Shaping

The most usual method of producing spur gears is by the "shaping" process, which employs principles entirely different from those just described. This time the cutter resembles a spur gear, having teeth similar to those which are to be cut into the blank (Fig. 2A): it is hardened and ground to very close dimensional limits, and the underside is recessed to provide the necessary cutting angles. It is mounted on a spindle (Fig. 1) having a vertical reciprocating movement or cutting stroke, the length of which can be adjusted to suit the width of the face of the blank. In addition, by means of change gears the cutter spindle is rotated whilst cutting is in progress.

The gear blank or blanks are mounted on a vertical arbor, which may be moved away from the normal cutting position to facilitate loading. Through suitable change gears the arbor is caused to rotate at the same speed as the cutter when cutting is in progress. Once set the machine is fully automatic, working without attention until the gear is finished, when a bell sounds and the driving motor stops.

When the machine is set into operation, the cutter moves up and down the face of the gear blank, just clearing it at the top and bottom. At the same time, both cutter and work commence to revolve in unison, and the cutter head moves along its slide, so that the cutter feeds into the blank. Just before the full

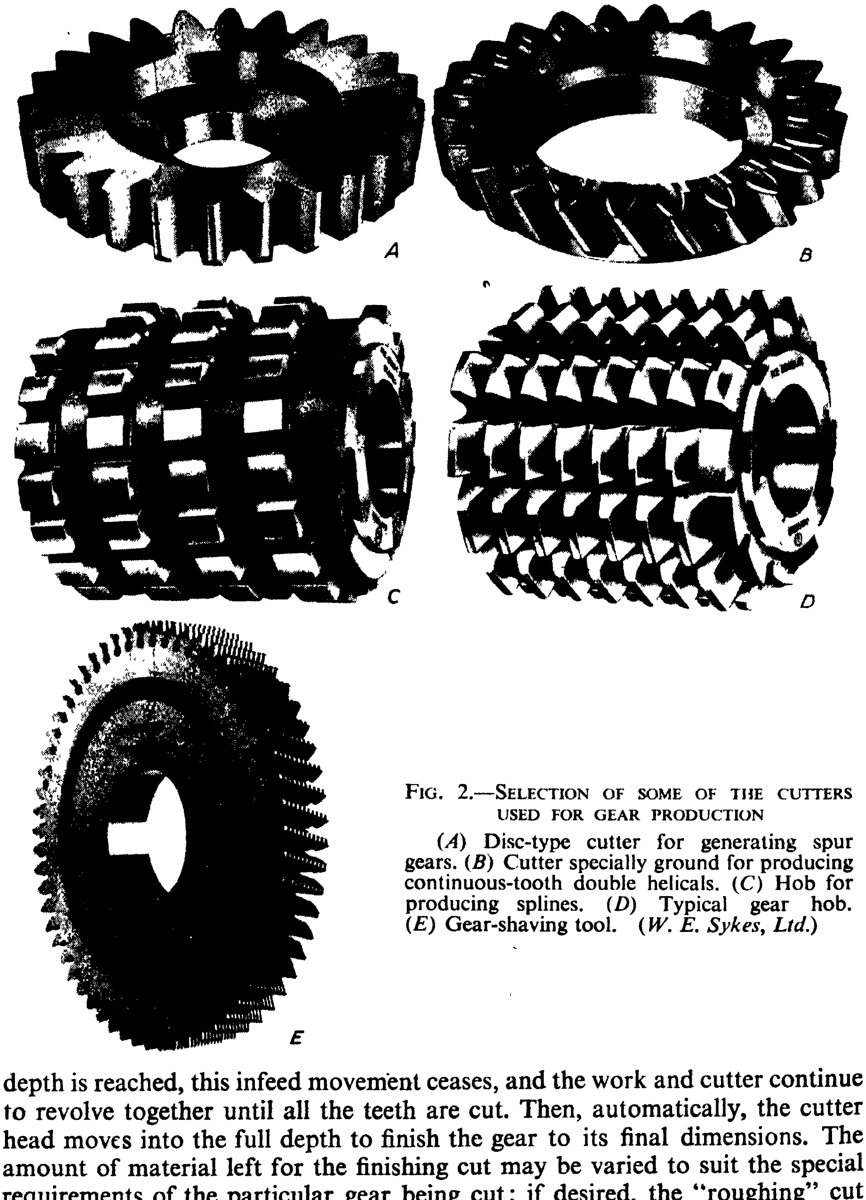

FIG. 2.—SELECTION OF SOME OF THE CUTTERS USED FOR GEAR PRODUCTION

(*A*) Disc-type cutter for generating spur gears. (*B*) Cutter specially ground for producing continuous-tooth double helicals. (*C*) Hob for producing splines. (*D*) Typical gear hob. (*E*) Gear-shaving tool. (*W. E. Sykes, Ltd.*)

depth is reached, this infeed movement ceases, and the work and cutter continue to revolve together until all the teeth are cut. Then, automatically, the cutter head moves into the full depth to finish the gear to its final dimensions. The amount of material left for the finishing cut may be varied to suit the special requirements of the particular gear being cut; if desired, the "roughing" cut can be omitted, and the gear cut to size during one revolution. On the other hand, more than one "roughing" stage could be used.

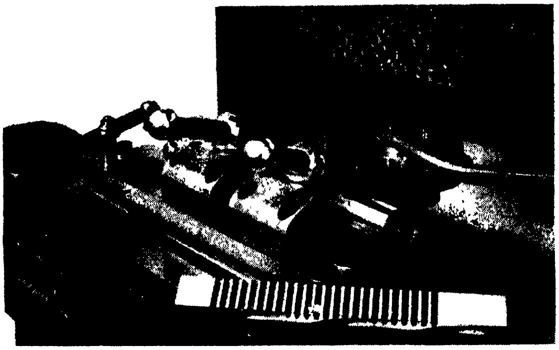

FIG. 3.—ATTACHMENT FOR ADAPTING A GEAR GENERATOR FOR CUTTING RACKS (*W. E. Sykes, Ltd.*)

The cutter can be mounted with the cutting face either upwards or downwards, so that it cuts on either the up or down stroke as desired. In the case of "cluster" gears, for example, where several gears are machined from a single solid blank, the small clearance between the gears would make down-stroke cutting essential (Fig. 1). On the other hand, the shape of the gear may make it more easier to cut on the up stroke. To lengthen the life of the cutting edges, either the cutter head or the work table automatically withdraws for a small amount on each return stroke.

It will be seen that these machines operate on the shaping principle, and for this reason are known as "gear shapers." Although there are slight design variations between the machines built by different manufacturers, the operating principles are in all cases broadly similar to those given above. An important feature about this type of machine is the fact that the cutting action resembles the rolling together of two gears in mesh. Consequently, a very high degree of accuracy is obtained, as well as an excellent quality of surface finish. As will be seen later, this principle, known as "generation," is employed in various forms for other types of gear cutting. In addition to their use for cutting external spur gears these machines are also suitable for cutting internal gears.

Certain makers have developed slightly modified versions capable of also cutting helical teeth up to 45°. The change-over is made very easily, and a cutter with helical teeth is used. By fitting a special attachment (Fig. 3) in place of the normal work-holding system, the machine can usually be arranged for cutting racks. In addition to gears, other types of work can be performed, such as cutting splines, keyways, sprockets, cams, ratchets, and a wide variety of both regular and irregular shapes. This is largely a matter of designing cutters with suitable contours.

Gear Planers

Somewhat similar principles to those given above are employed for a type of machine known as a "gear planer." In this case, however, the cutter resembles a short, straight section of a gear rack which is reciprocated across the face of the gear blank. Whilst cutting is in progress, the blank rotates slowly and the

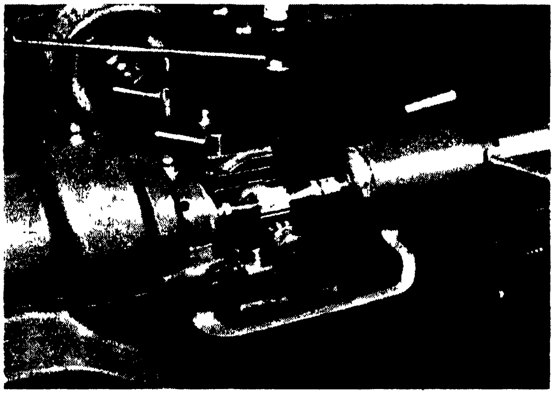

Fig. 4.—The cutter and work on a small gear-hobbing machine

cutter moves at right angles, giving the effect of a gear rolling along a rack. Both vertical and horizontal types are available, the former being rather similar in appearance to a slotting machine.

The Hobbing Process

The hobbing method of gear generation, which employs a type of cutter known as a "hob," is completely different from the shaping technique: in appearance, the hob (Fig. 2D) rather resembles a spiral or worm with teeth cut along its length. Both horizontal and vertical machines are available, but the following remarks apply equally to both types.

The machine (Fig. 4) is so designed that the gear blank rotates as the cutter feeds across its face, the relative speeds of work and cutter rotation being closely controlled by change gears. The shape of the hob teeth, of course, vary according to the size and type of tooth being cut.

Hobbing machines are suitable also for cutting helical gears, wormwheels, splined shafts, chain sprockets, and other types of work. In the case of helical gears, the operating principle is the same as for spur gears, except that the hob slide is set over at an angle (Fig. 5). When cutting wormwheels, however, after feeding in to depth, both hob and blank rotate in fixed positions. In this particular case, the effect is practically the same as when a worm and wormwheel rotate together in mesh.

HELICAL GEARS

Most types of machines suitable for cutting straight-tooth spur gears may be adapted for cutting helical teeth, and several examples of these have already been given. Certain types of gear-generating machines which, although primarily designed for cutting all types of external and internal helical gears, can also be employed for straight-tooth gears, splines, cams, and racks. Basically, the machine is a gear shaper with circular cutters which, instead of vertical move-

FIG. 5.—HOBBING LARGE DOUBLE HELICAL PINIONS FOR ROLLING-MILL DRIVES
(David Brown-Jackson, Ltd.)

ment, reciprocate along horizontal slides. When cutting helical teeth, the necessary movement is given to the cutter by helical guides, which are replaced by straight guides when cutting spur gears.

To enable the production of herringbone or double-helical gears, two cutter heads are provided, one of which can be removed when cutting spurs or single helical teeth. These cut towards the centre, one head moving forward as the other withdraws. The design is such that, if necessary, one head will cut helical teeth and the other straight teeth of the same pitch and number simultaneously. Provided the blanks are spaced with a clearance between each, two or more cutters may be carried on each head, so that four or more gears are cut simultaneously: in this case the machine is so set that each cutter cuts one gear. Both external and internal gears can be handled, the latter requiring a different type of tool comprising a cutter on a sturdy shank. By fitting a special attachment, both straight and helical tooth racks can be produced.

Milling Process

For repair work or very small quantities, helical gears may be produced on a universal milling machine. The table is swivelled to the appropriate spiral angle, and the dividing head connected to the table lead screw by a train of gears; also, the plunger is withdrawn from the index plate. By this means, the

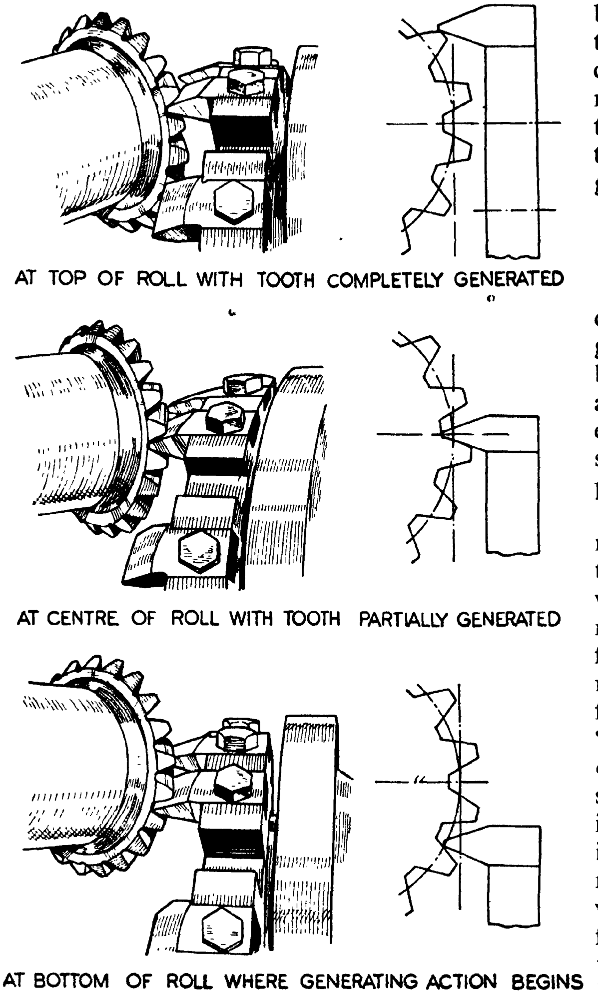

FIG. 6.—GENERATING ACTION OF SPIRAL BEVEL-GEAR GENERATOR

blank is rotated as the table advances to the cutter. Calculations are necessary to determine the number of teeth in the various gears to give the required spiral.

WORMS AND WORMWHEELS

Worms are not produced by any of the gear-cutting processes, but are either turned in a lathe or machined on equipment developed specially for the purpose.

There are several methods of machining the teeth in the wheel with which the worm meshes, one being performed on a universal miller. The teeth are first "gashed" or "roughed" with an ordinary gear cutter of suitable size. The dividing-head spindle and index plate are disconnected, so that the wormwheel may be freely rotated by hand; the cutter is replaced by a hob of the type mentioned earlier. The machine table is now slowly raised until the revolving hob engages the teeth gashed in the wormwheel, causing it to rotate in the same manner as a worm and wheel in engagement. By continuing to raise the table carefully, the hob cuts into the blank until the correct depth is reached.

It must be emphasised that this is only a makeshift method which should not be employed unless unavoidable. To obtain accurate results, both the wheel and hob should be driven at their correct relative speeds, as on a hobbing

machine; in the case just mentioned this is not so, as only the hob is driven. The quickest and most accurate method of producing wormwheels is on a hobbing machine or one of the other types already mentioned.

BEVEL GEARS

Bevel gears can only be cut satisfactorily on machines designed specially for the purpose, due largely to the fact that the width and depth of the teeth vary uniformly from one end to the other. These employ two reciprocating tools, one on each side of the tooth, and are known as either bevel-gear shapers or generators.

Gleason Cutters

In the case of the well-known Gleason range, two reciprocating side-cutting tools move along slides located on the front of a circular cradle which, in turn, rotates about its axis in a timed relation to the work spindle carrying the gear blank. By rolling the gear tooth in this manner (Fig. 6) between two reciprocating tools representing sides of adjacent teeth in an imaginary mating crown wheel, the tooth profile is generated. As each tooth is completed, the work moves clear from the cutters, the former then automatically indexing to the next tooth position. This continues until the gear is finished, the machine then automatically stopping.

This machine may be used both for roughing and finishing. For the former, tools of different shape are fitted, and the generating motion is cut out, the blank being fed straight into the teeth. When the quantities are sufficiently large, special automatic machines are provided solely for roughing operations. These are of completely different design from those for finishing, and employ a horizontal rotating disc-type cutter with inserted teeth. Each tooth or "blade" is of slightly different shape, so that those which cut at the large end of the gear blank are wider than those cutting at the small end. Thus, by a combination of blade form and the method of feeding the cutter into the work, a close approximation of the taper and profile of the final tooth form is produced. These machines are capable of very high outputs.

Although, in an emergency, bevel gears may be cut on horizontal milling machines, it is impossible to obtain the correct tooth form, and a certain amount of filing is always necessary. Some firms have developed special attachments enabling bevel gears to be produced on an ordinary shaping machine.

Spiral Bevel Gears

The term "spiral bevel" is used here in its general sense, but it should be noted that there are several different types of bevel gears with curved teeth. These include Zerol and hypoid gears, the former being the trade name for a patented type with curved teeth having zero spiral angle. With pure spiral bevels the pinion is mounted on the same centre line as the crown wheel (Fig. 7), whilst the pinion for hypoids is offset above or below the centre line

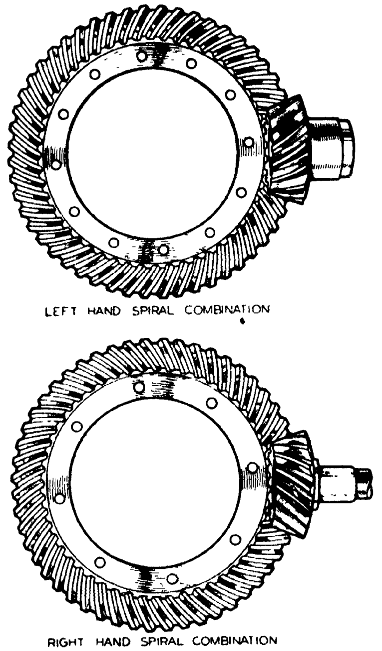

FIG. 7.—LEFT- AND RIGHT-HAND SPIRAL COMBINATIONS

(Fig. 8). Each type has its own particular applications for different methods of driving.

Spiral bevel gears can only be produced on machines developed specially for the purpose. The teeth are generated, using a rotary cutter which is very similar to a face mill, the inserted cutters or blades being accurately ground to a special shape. The machine operates on somewhat similar principles to the straight-tooth bevel-gear generator, the tooth profile being produced by rolling the rotating cutter together with the blank as if two gears were in mesh; the cutter represents one tooth. The machines are fully automatic, and cease operation when the last tooth is finished. For production purposes, separate machines are employed for cutting pinions and wheels, and also for roughing and finishing.

GEAR FINISHING

To ensure smooth running and maximum life after cutting the teeth, many gears are hardened and then ground. Care is necessary when hardening and quenching in order to avoid excessive distortion which may prevent the teeth from "cleaning up" during subsequent grinding. For larger, flat gears, such as bevel crown wheels, special "quenching presses" are available which practically eliminate all distortion.

The work is clamped between upper and lower dies, and thus straightened whilst still hot and plastic. Held in this manner, the quenching oil is then forced uniformly over and around the gear, the design of the dies being such as to allow normal contraction. The rate of quenching can be regulated to suit the size and type of gear involved. The incorporation of an automatic cycle ensures that when large quantities are involved all parts receive uniform quenching. A variation of this machine has also been developed for hardening small pinions.

Surface Hardening

Another type of hardening is sometimes employed for gears, this comprising local surface hardening by means of an oxy-acetylene flame. This process, which only penetrates the surface of the teeth and does not affect the body of the gear, is performed on special machines. The design varies according to the type of gear involved, special models being available for hardening straight-bevel and spiral-bevel types.

These incorporate two oxy-acetylene burners, one on each side of the tooth, giving simultaneous hardening of both faces. By means of an hydraulic burner speed control, uniform penetration, i.e. hardness, is obtained at the tooth ends and throughout the whole length. Since only a small section of the tooth is heated at any one time, the heat is rapidly diffused through the gear body, thus reducing distortion to a negligible amount, this diffusion being assisted by continuously spraying copious jets of water over the gear. The design is such that the burners automatically traverse along the length of the tooth, and in the case of spiral teeth suitable mechanism is incorporated to provide the curved movement. On some machines, the gears are manually indexed from tooth to tooth, whilst on the other models this is performed automatically.

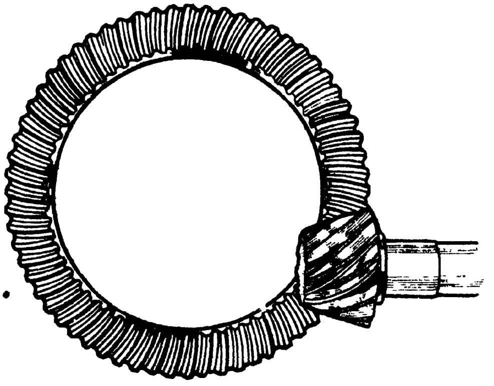

FIG. 8.—HYPOID GEAR AND PINION

Grinding

The type of machine employed for tooth grinding varies according to the style of gear. For instance, straight-tooth spur gears are often ground with a wheel shaped exactly to the same contours as the tooth; the machines are automatic, the gear indexing after each passage of the wheel. A diamond device, generally controlled by a template of the same profile as the tooth, automatically trues the wheel and compensates for wear.

Another type of machine employs two thin disc wheels. By suitable mechanism an effect similar to rolling the gear along a rack is obtained: this, of course, is the generating principle. The machine is fully automatic, and the wheels are continuously trued by diamonds.

Gleason Hypoid Grinder

A very interesting automatic machine has been developed specially for grinding the teeth of all types of spiral bevel gears. It employs the familiar generating principle used on the Gleason bevel-gear generators, in which a relative motion of the work and the wheel-carrying cradle automatically generates the correct tooth shape. This motion corresponds to that of a gear rolling with a crown gear, of which the wheel represents a single tooth. While maintaining the same principle of generation, the method of operation is wholly different from any formerly used, in that it combines a continuous rotation of the work spindle with a timed, reciprocating rolling motion of the wheel-carrying cradle.

FIG. 9.—A SIMPLE GEAR-TESTING FIXTURE INCORPORATING A DIAL-TYPE COMPARATOR

The machine cycle is as follows: the wheel is fed in to full depth, and meshes with the work at the beginning of the up-roll of the cradle during which grinding takes place. It is then withdrawn for the down-roll, while the work rotates continuously to produce the index, so that the wheel, when it begins on the next up-roll, engages a following tooth. The automatic cycle then provides for automatic in-feed of the sliding base by the proper amount and sequence between grinding passes and automatic dressing of the grinding wheel at the proper place between passes. After completion of the predetermined number of passes necessary to secure the desired results for the particular job, the machine is automatically stopped.

Grinding is done with pot-type wheels varying from 6 in. to 13½ in. diameter, according to the size of gear being ground. The wheel speed varies from 5,500 to 8,800 surface feet per minute, according to the conditions. Wheel truing is carried out by means of three diamonds—one for the external tapered portion at the end, another for the tip radius, and the third for the internal diameter. The three arms carrying the diamonds are mounted on two attachments, and all swing simultaneously into their various dressing positions.

Before dressing commences, the wheel automatically feeds outwards for a distance of 0·001 to 0·003 in. to ensure cleaning up to the correct dimensions. It will be realised that the accuracy of the gear after grinding is largely influenced by the accuracy of the wheel sizes. The amount of projection may be pre-set to anywhere between the above limits. The three arms then swing forward with different movements—and, if desired, different speeds—to dress their respective wheel faces.

At the end of the forward stroke of the diamonds, the speed of the arm movement is automatically reduced in order to provide a fine dressing cut on the return stroke. In actual practice it is usual first to rough grind the teeth and then dress the wheel for a second or finishing cut over all the teeth. The wheel is then used without redressing for rough grinding the next gear.

Burnishing and Lapping

Another method of finishing gears is by "burnishing." For this the gear is run in mesh with a hardened "master" gear, thus correcting any slight inaccuracies and also producing a highly polished surface. A rather similar process, particularly suitable for spur and helical teeth, consists of lapping mating pairs of gears together. It has been found that the best results are obtained if the axis of the two gears are crossed, instead of parallel.

Spiral bevel and hypoid gears are generally lapped after hardening, unless they are to be ground, to provide a high polish on the tooth surfaces. This is accomplished by running the gear and pinion under light load while a mixture of oil and abrasive is pumped to the point of tooth contact. This operation is done on special machines which are fully automatic and so designed that the lapping action extends over the whole surface of the tooth. One manufacturer has incorporated a pre-set backlash control which automatically maintains the same backlash once the correct centre distance has been determined. It should be noted that lapping is employed only to improve the tooth surface and correct slight hardening defects. It is not suitable for salvaging faulty gears.

Gear Shaving

During recent years several manufacturers have introduced new and improved types of shaving machines for finishing spur and helical teeth. This process removes any errors arising from previous operations, and results in gears of the highest possible accuracy.

Slightly different methods are employed by the various manufacturers but, in general, the process consists of rotating a cutter and gear in mesh, at the same time moving the work across the cutter with either a sliding or a reciprocating movement. The cutter (Fig. 2*E*) is somewhat similar in appearance to a helical gear: each tooth is serrated in such a manner as to provide a series of cutting edges which shave away any high spots or other inaccuracies as it rotates with the gear. Only a very small amount of metal is removed. Most machines employ the "crossed axis" technique mentioned earlier. A single cutter is usually suitable for all gears of the same pitch and pressure angle.

Inspection

The main tooth dimensions are checked in the production department with callipers such as shown in Fig. 9. In the inspection department, however, use is generally made of special types of comparators previously set to a master gear. These are often built into fairly elaborate jigs, which enable all the principal dimensions to be checked in a few seconds. When the quantities are sufficiently large, special testing machines, often incorporating a master gear with which the production gear is rotated, are employed. These are sometimes designed so that the gear and its mating pinion are run together in mesh for the dual purpose of checking the accuracy of the gears and also running-in.

J. A. O.

GRINDING MACHINES

THE progress of grinding practice and machines has been more rapid than any other branch of the engineering industry, and during the last few years grinding machines have developed from a light tool used only for occasional and special work, into a production machine of massive design intended for continuous hard use on precision work of the finest nature. In the modern machine shop the usual limits of accuracy for mass-production grinding is $\frac{1}{10000}$ part of an inch (0·001).

This article gives a survey of the machines available for surface, cylindrical, internal, spline-shaft, and thread grinding. The characteristics of grinding wheels are described in "Tool-room Grinding," page 446.

In view of the importance of centreless grinding in modern mass-production work, this subject is dealt with at the end of the present section.

SURFACE GRINDING

Surface grinding machines are used to grind flat surfaces, the wheel rotating in a fixed position, whilst the work moves either backwards and forwards or in a rotary direction, according to the type of machine in use. There are three distinct types of surface grinding machines: horizontal, face, and rotary, each being capable of handling certain classes of work more efficiently than the other two.

Horizontal Machines

Fig. 1 illustrates a small tool-room type of modern horizontal spindle surface grinder. These machines are very accurate, the various controls being capable of adjustment to 0·0001 in.

The particular machine illustrated is described as an 18-in. × 6-in. size, which means that the maximum stroke or movement to the right and left is 18 in., whilst the cross-slide movement, in and out, has a maximum length of 6 in. Three hand-wheels control the movements, the one visible on the extreme left being for the hand operation of movements to the left and right. By lifting the lever situated below this hand-wheel the movement becomes automatic, that is, the table moves without attention from the operator, the length of stroke being controlled by the distance apart of the two reversing dogs visible on the right half of the table edge. The speed can be varied from any figure up to 30 ft. per minute, the small lever below the right wheel being used to change from the fast to slow range of speeds. This hand-wheel (extreme right) raises or lowers the table, the wide collar being marked with Vernier readings enabling movements of $\frac{1}{10000}$ in. to be made with great ease.

FIG. 1.—CHURCHILL MODEL NB HORIZONTAL-SPINDLE SURFACE GRINDER
Table surface 18 in. × 6 in.; table to new wheel, 9 in.

Directly above this hand-wheel is the reversing lever, which is knocked over by the dogs at the end of each stroke. The centre hand-wheel moves the table in and out, the lever just to the right being used to change from hand to automatic control when facing across flat surfaces.

Magnetic Chucks

A very large percentage of surface grinding work consists of grinding one, or both, sides of flat objects, and for this class of work it is usual to use a magnetic chuck, which supplies the only successful solution for holding these articles.

Magnetic chucks are either oblong or circular in shape, the latter usually being constructed as part of the machine and rotates with the workpiece. The other type is portable, being fastened to the machine table by two small bolts, and can easily be removed if another fixture is to be used. Two methods are used to provide the necessary magnetism, one by the use of an electric current and the other by a special arrangement of permanent magnets. With the former type the action of switching on the current causes the chuck to become magnetic and hold the work.

Non-electric magnetic chucks have become very popular during the last few years, and whilst possessing the same holding capacity as the electric type, have the distinct advantage of being free from encumbering wires.

Special care is required when using a magnetic chuck to hold pieces of thin material, as the magnets pull the bottom surface of the work flat on the chuck. Thus, if the thin workpiece is slightly bent before grinding, it will be pulled straight by the magnets, but when removed from the chuck will spring back

into its original shape. The only method to obtain a level surface is to "pack up" with strips of tinfoil any hollow places before the magnetism is applied.

Sometimes a knee plate is bolted to the table to hold articles which are not suitable for a magnetic chuck; or a vice or other fixture can be used, the method varying according to the shape of the work.

General Hints

The limits for accuracy are very close, usually in the region of 0·001 in., so it is very important that every precaution should be taken to obtain accurate settings, for even the most perfect machine will give inaccurate results if carelessly "set up." Before fastening the chuck, vice, or fixture to the table, the table surface and base of the holding device should be carefully wiped free from all dirt, oil, etc., as a very small speck will cause an error of at least one-thousandth of an inch, which is ten times larger than the usual tolerance allowed when surface grinding. Neglect of this very elementary precaution is responsible for a large percentage of faulty surface grinding work.

A very useful check when using a magnetic chuck is to fasten a dial indicator to a rigid part of the wheel head and run the pointer over the surface to ensure that it is absolutely level. If a knee plate is to be used, the pointer should be brought into contact with the vertical face and then, by raising or lowering the machine table, the indicator will show if the knee plate is absolutely square.

When the work is correctly set for grinding, the stops controlling the length of movement or "stroke" of the table should be set to approximately the correct positions and, after making certain that the wheel will not foul the work or fixture, the machine should be set in motion. It will now usually be found that the table stops are not set correctly and that further adjustment is necessary so that the work just passes clear from the wheel by a small amount at the end of each stroke. This adjustment should only be made when the machine is stopped, as the practice of altering the stops while the table is moving often causes serious mishaps, even when done by experienced operators.

Great care is necessary when raising the table to bring the wheel into contact with the work, as both the wheel and work are in motion. When the wheel is obviously nearly in contact the table should only be raised 0·001 in. for each stroke of the table to avoid a "smash-up" caused by hitting the work with a heavy blow. As soon as contact is made the table movement should be stopped at the end of a stroke and the table wound forward until the work is clear of the wheel.

The habit of winding the table across while it is moving backwards and forwards often causes mishaps, due to irregularities on the surface. After the first cut has been taken over the surface, it is then quite safe to wind the table across when it is moving. In comparison with other machine tools, very little material is removed, the cuts consisting of only a few thousandths of an inch.

Directly above this hand-wheel is the reversing lever, which is knocked over by the dogs at the end of each stroke. The centre hand-wheel moves the table in and out, the lever just to the right being used to change from hand to automatic control when facing across flat surfaces.

FIG. 1.—CHURCHILL MODEL NB HORIZONTAL-SPINDLE SURFACE GRINDER

Table surface 18 in. × 6 in.; table to new wheel, 9 in.

Magnetic Chucks

A very large percentage of surface grinding work consists of grinding one, or both, sides of flat objects, and for this class of work it is usual to use a magnetic chuck, which supplies the only successful solution for holding these articles.

Magnetic chucks are either oblong or circular in shape, the latter usually being constructed as part of the machine and rotates with the workpiece. The other type is portable, being fastened to the machine table by two small bolts, and can easily be removed if another fixture is to be used. Two methods are used to provide the necessary magnetism, one by the use of an electric current and the other by a special arrangement of permanent magnets. With the former type the action of switching on the current causes the chuck to become magnetic and hold the work.

Non-electric magnetic chucks have become very popular during the last few years, and whilst possessing the same holding capacity as the electric type, have the distinct advantage of being free from encumbering wires.

Special care is required when using a magnetic chuck to hold pieces of thin material, as the magnets pull the bottom surface of the work flat on the chuck. Thus, if the thin workpiece is slightly bent before grinding, it will be pulled straight by the magnets, but when removed from the chuck will spring back

into its original shape. The only method to obtain a level surface is to "pack up" with strips of tinfoil any hollow places before the magnetism is applied.

Sometimes a knee plate is bolted to the table to hold articles which are not suitable for a magnetic chuck; or a vice or other fixture can be used, the method varying according to the shape of the work.

General Hints

The limits for accuracy are very close, usually in the region of 0·001 in., so it is very important that every precaution should be taken to obtain accurate settings, for even the most perfect machine will give inaccurate results if carelessly "set up." Before fastening the chuck, vice, or fixture to the table, the table surface and base of the holding device should be carefully wiped free from all dirt, oil, etc., as a very small speck will cause an error of at least one-thousandth of an inch, which is ten times larger than the usual tolerance allowed when surface grinding. Neglect of this very elementary precaution is responsible for a large percentage of faulty surface grinding work.

A very useful check when using a magnetic chuck is to fasten a dial indicator to a rigid part of the wheel head and run the pointer over the surface to ensure that it is absolutely level. If a knee plate is to be used, the pointer should be brought into contact with the vertical face and then, by raising or lowering the machine table, the indicator will show if the knee plate is absolutely square.

When the work is correctly set for grinding, the stops controlling the length of movement or "stroke" of the table should be set to approximately the correct positions and, after making certain that the wheel will not foul the work or fixture, the machine should be set in motion. It will now usually be found that the table stops are not set correctly and that further adjustment is necessary so that the work just passes clear from the wheel by a small amount at the end of each stroke. This adjustment should only be made when the machine is stopped, as the practice of altering the stops while the table is moving often causes serious mishaps, even when done by experienced operators.

Great care is necessary when raising the table to bring the wheel into contact with the work, as both the wheel and work are in motion. When the wheel is obviously nearly in contact the table should only be raised 0·001 in. for each stroke of the table to avoid a "smash-up" caused by hitting the work with a heavy blow. As soon as contact is made the table movement should be stopped at the end of a stroke and the table wound forward until the work is clear of the wheel.

The habit of winding the table across while it is moving backwards and forwards often causes mishaps, due to irregularities on the surface. After the first cut has been taken over the surface, it is then quite safe to wind the table across when it is moving. In comparison with other machine tools, very little material is removed, the cuts consisting of only a few thousandths of an inch.

machine is not very common, and is usually only found in works manufacturing fairly large articles.

Rotary Table Surface Grinders

Fig. 3 illustrates yet another type of surface grinder, the vertical rotary table machine. In general, this machine consists of a circular table capable of rotation, and a large segmental grinding wheel which revolves at a very high speed in the opposite direction to the table. The machine is quite simple in operation, as it is only necessary to fasten the work to the table, set it in rotation, and lower the grinding wheel until it makes contact with the work.

Large guards are fixed around the table, as a considerable amount of water, used for cooling, is thrown out by the revolving work. Two different types of tables are to be found on these machines, magnetic and non-magnetic. In Fig. 3 a non-magnetic table is seen, the castings being held by bolts and clamps. This is the usual method for holding down work which is fairly high,

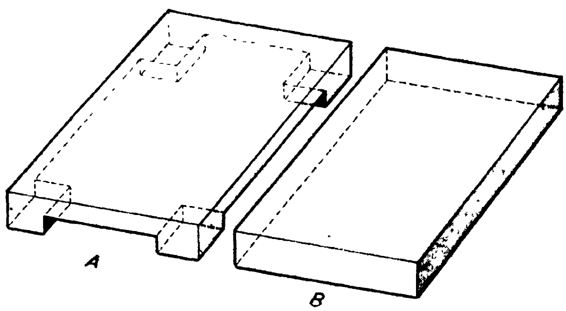

FIG. 4.—USE OF MAGNETIC CHUCK

A and *B* are two plates of approximately the same dimensions. The solid plate *B* can be securely held on a magnetic chuck, as it will offer a considerable surface area to the magnets. Plate *A* cannot be held by this method, as only the four corner pieces would be in contact with the magnetic surface.

as the magnetic table would not hold it securely enough to withstand the pressure exerted by the wheel.

Work which is not high in relation to its area can be held quite safely with a magnetic chuck, as the holding-down qualities of the latter depend upon the amount of metal on which the magnet can act. Thus a piece of plate could be securely held with a magnetic table, but another piece of metal, of the same over-all dimensions, could not be held if it was recessed inside (see Fig. 4), so that the amount of surface area in actual contact with the magnet was considerably less. This fact is very important when deciding which method to use for holding any particular article.

CYLINDRICAL GRINDING

Cylindrical grinding consists of grinding cylindrical work, such as round bars, etc., and differs from surface grinding in the fact that the work revolves, as well as the wheel, but in the opposite direction. A general idea of the machine can be gained from Fig. 5. Work can be accurately ground to any desired taper by swivelling the table around to the necessary angle, whilst for oval work it is

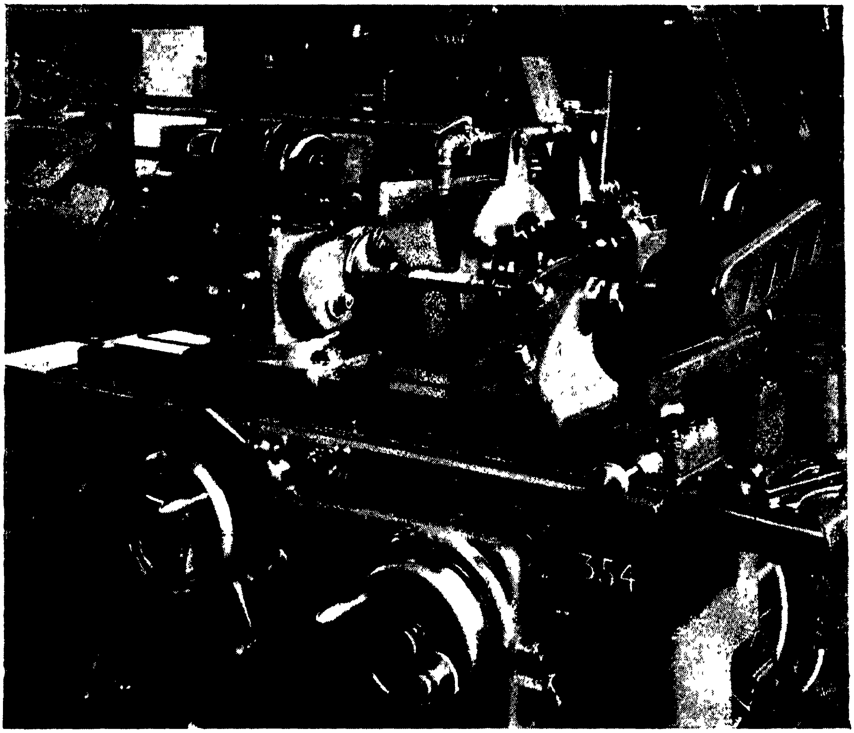

FIG. 5.—CYLINDRICAL GRINDING MACHINE SET UP FOR GRINDING PNEUMATIC HAMMER PARTS
(*Broom & Wade, Ltd.*)

now possible to obtain attachments to enable this to be carried out to a remarkable degree of accuracy.

General Hints

The beginner often experiences difficulty in grinding long articles so that they are absolutely parallel, usually finding that one end is a few thousandths of an inch larger than the other. This is due to the table being slightly swivelled "out of truth," although the zero mark at the end of the table appears to be set in the correct position; but when it is realised that the thickness of the hairline graduations on the scale will cause an error of 0·005 in., the need for special precautions will become evident.

When commencing work on a strange machine or starting work on a parallel job after the table has been previously moved for tapered work, the following procedure should be adopted. First, carefully set the table to "zero," tighten the bolts, insert a piece of bar, and then take one or two light cuts along the work until it is "cleaned up" over its entire length. Stop the machine and

carefully measure both ends with a micrometer, and the difference between the diameters will give approximately double the error of the table. Thus, if the difference is 0·006 in., the table requires swivelling around 0·003 in. (see Fig. 6) and another trial cut should be taken over the bar to check the new setting.

Once the table is accurately set, every article will be ground absolutely parallel without further attention. If there is plenty of material to be removed from the article, it can be used instead of a bar for setting purposes if care is taken to keep well above the final dimensions, to avoid spoiling it. When moving the table to obtain the true setting, it is necessary first to attach a dial indicator to some suitable part of the machine (but not to the table) and put the pointer in contact with one end of the work (before loosening the holding bolts) so that the exact measurement can be obtained of the movement of the table.

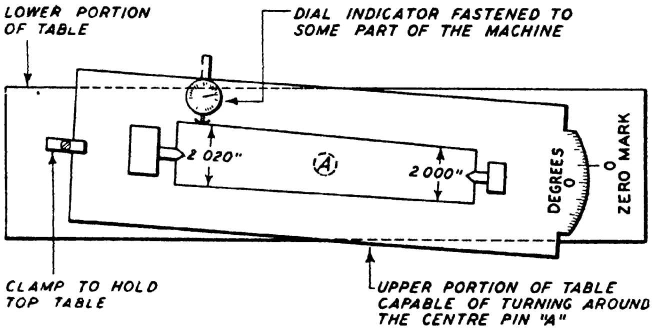

FIG. 6.—DIAGRAMMATIC PLAN VIEW OF METHOD USED TO SET THE TABLE OF A CYLINDRICAL GRINDING MACHINE

Note, if the test bar shows a taper of 0·020 in. it will be necessary to move the table until the dial records a movement of 0·010 in. Note also the use of the scale to set the tables to any required angle.

INTERNAL GRINDING

Internal grinding consists of grinding the inside surface of holes. There are two main types of machines, one for work which can be revolved and the other for larger work, such as cylinder blocks, which must be held stationary on a table.

A general idea of the first type of machine can be obtained from Fig. 7. A chuck or faceplate is fixed to the left end of the table and can be rotated by a motor or from a belt. Removable guards are usually provided to surround the chuck, to protect the operator from the water thrown out as it revolves.

Fixed on a sliding saddle at the other end is a spindle with a grinding wheel attached to the end, which also revolves, but in the opposite direction to the chuck. This spindle can be wound across the table by the handwheel visible at the front, and by moving the spindle outwards (i.e. towards the operator) the hole is ground to a larger diameter. The whole saddle carrying the spindle can move lengthways (i.e. to and from the work), this movement being automatic

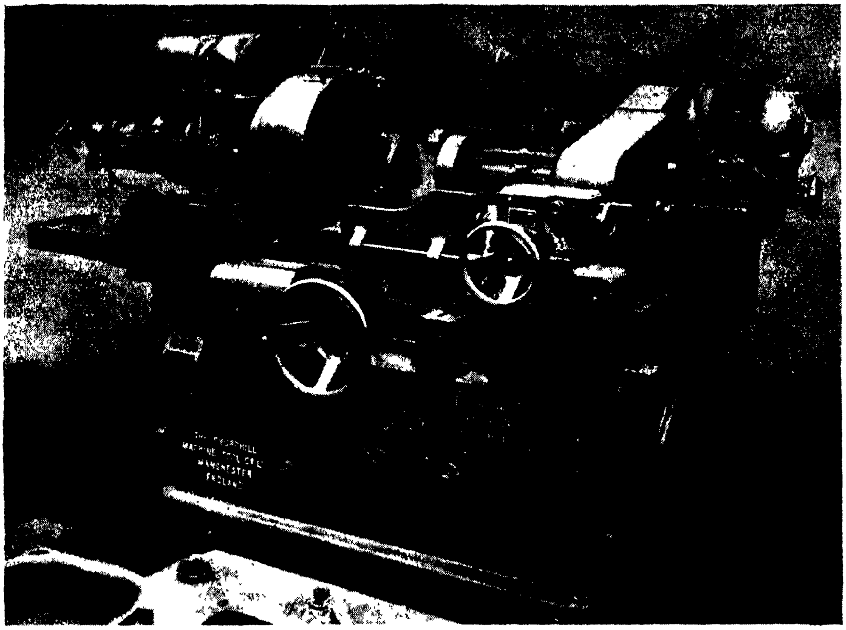

FIG. 7.—CHURCHILL MODEL HBB AUTOMATIC SIZING INTERNAL GRINDING MACHINE

and controlled by two stops or dogs set so that the wheel just passes through the hole.

Thus, when in operation, the work revolves in one direction, and the wheel, revolving at a very high speed in the opposite direction, is passing quickly in and out of the hole, grinding a few thousandths of an inch at each passage. The cross-feed to enlarge the hole can be operated either by turning the hand-wheel or by an automatic device which moves the wheel without attention from the operator.

The particular features of the machine shown in Fig. 7 are as follows:

The independent speed control to the table traverse is incorporated for wheel truing and grinding, which also provides a high independent run-in and run-out speed to cut out idle time.

Automatic hydraulic feed is provided to ensure a suitable rate of cross feed with short table traverse.

When grinding short bores and blind holes, the reversing stroke can be suitably adjusted.

Hand motion is only used for the setting of the machine, all motions being fully automatic after this initial setting.

The grinding-wheel feed is controlled to 0·001 in. by a precision micrometer stop.

Cylinder Grinding Type

The other type of internal grinding machine often used for grinding cylinders, etc., varies considerably from the previously described machine. This time the work cannot rotate, as it is too large and heavy; also, because the work does not rotate, the hole cannot be enlarged by moving the table outwards (Fig. 8), as this would merely disfigure the work.

From the illustration it can be seen that the machine consists of a long spindle carrying the grinding wheel, and a flat table which can move outwards or to and from the wheel. The lengthways movement can be controlled by stops, so that the work is fed quickly to and from the wheel, giving a similar move-

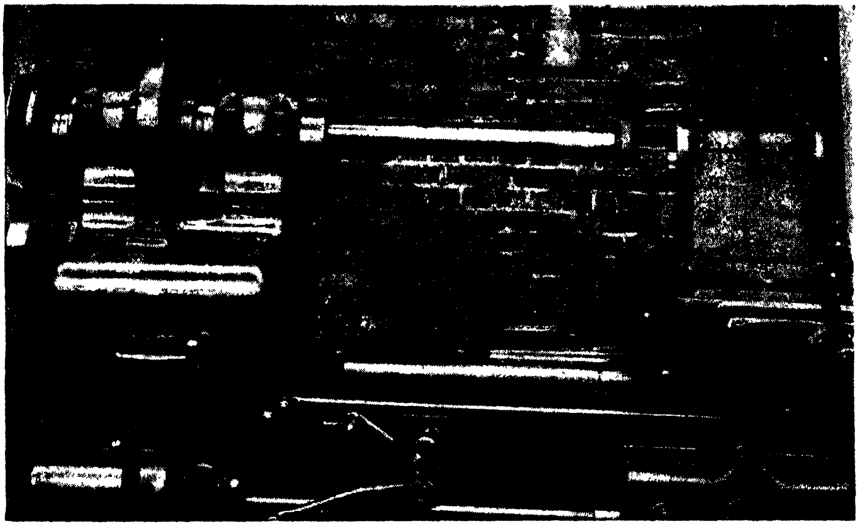

FIG. 8.—CYLINDER GRINDING MACHINE SET UP TO GRIND OUT THE BORE IN A CASTING
(Broom & Wade Ltd.

ment to that obtained on the previous machine. The grinding spindle rotates on a large circular head.

By turning a hand-wheel the spindle can be made to move outwards, thus describing a larger circle as it revolves and consequently grinding out the hole to a larger diameter.

Sometimes this type of machine is built so that the table moves towards the wheel, whilst others are constructed so that the table is stationary and the entire head carrying the spindle moves towards the work, but in all other respects they are similar.

Alternative Form of Internal Grinder

It will be noticed in previous references to internal grinding that it is customary to use a wheel which is very much less in width than the length of

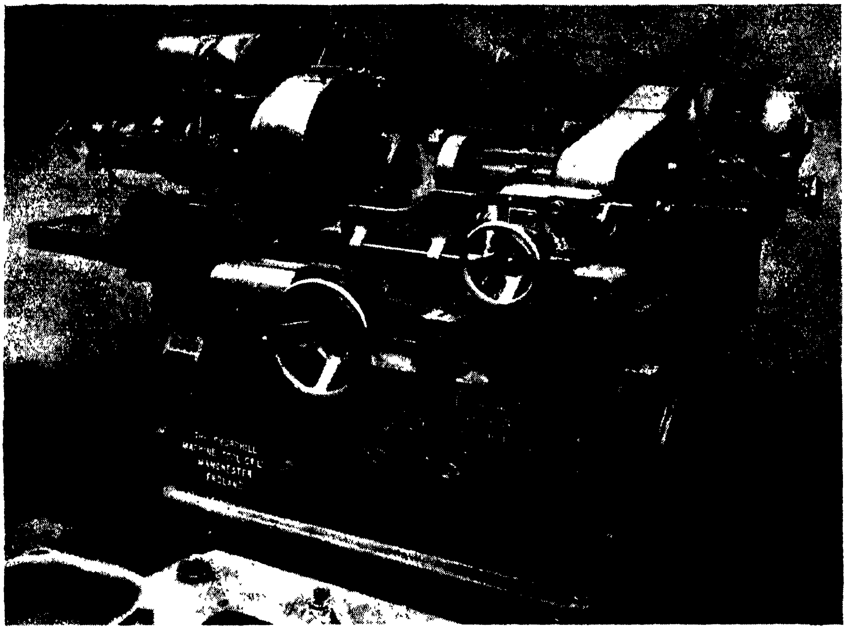

FIG. 7.—CHURCHILL MODEL HBB AUTOMATIC SIZING INTERNAL GRINDING MACHINE

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When grinding short bores and blind holes, the reversing stroke can be suitably adjusted.

Hand motion is only used for the setting of the machine, all motions being fully automatic after this initial setting.

The grinding-wheel feed is controlled to 0·001 in. by a precision micrometer stop.

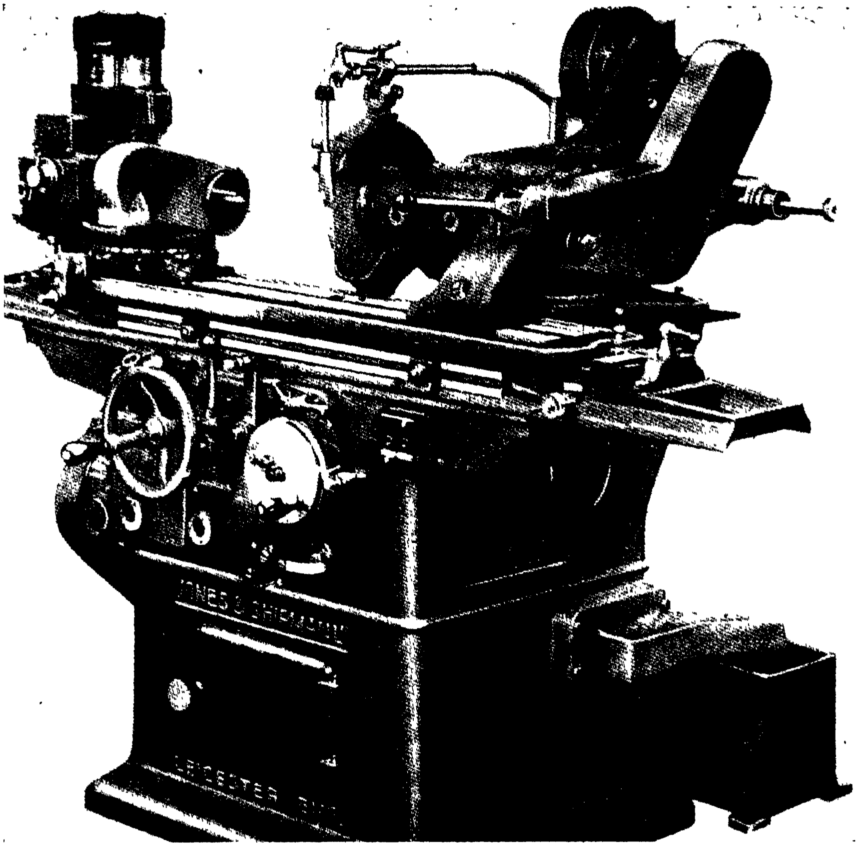

FIG. 9.—UNIVERSAL GRINDER
The table and the work head can be swivelled round to suit the shape of the work.
(*Jones & Shipman, Ltd.*)

machine will not often be found in the production shop, as it is intended more for universal toolroom work.

SPLINE-SHAFT GRINDING MACHINES

Special-purpose machines are now made to grind spline shafts used for the sliding gears in gearboxes. Methods of grinding the various types of spline shafts are given in Figs. 10 and 11. The number of splines usually varies between two and sixteen. The shafts are machined out on milling machines to within 0·015 in. of the required size, after which they are hardened, in preparation for grinding.

Fig. 12 shows an automatic spline-shaft grinding machine capable of

handling work up to 5 ft. in length by 13 in. in diameter. The table is only capable of movement in one direction, lengthways, hand-feed operation being obtained from the one wheel visible on the left; this can be changed into automatic movement by pulling forward the lever on the right side of it. Alteration in the wheel-head height can be obtained to suit varying diameters of shafts.

On the right end of the table is an automatic dividing head which can be set to index any number of equally spaced divisions from two to sixteen. From the head a lever is fixed to make contact with an adjustable dog bolted to a slide underneath, whilst a short distance along the table edge can be seen two more adjustable dogs. These two latter dogs are set so that the table can only move with the correct stroke to suit the length of the work, the direction of movement being reversed each time a dog makes contact with a plunger.

At the end of each stroke, i.e. when the table has run to the right so that the wheel is clear of the work, the dividing-head lever catches the dog and causes the head to index to the next position. Note that the spline shafts are intended to be held between centres, as both headstock and tailstock (second from left end of table) are equipped with centres only.

Two Methods of Spline-shaft Grinding

Two methods of spline-shaft grinding can be employed, using either one or three grinding wheels. For shafts with a blind end, i.e. where the spline is not milled the complete length, it is only possible to use a single wheel shaped to suit the spline, but in cases where the splines are cut the full length of the shaft, it is possible to use three wheels (Fig. 11), thus obtaining greater efficiency.

As can be understood, the wheels will soon lose their shape, and unless some quick and accurate method can be provided to true the wheels without losing the accurate "setting," the machines will be useless. This wheel truing is done by a clever device, seen on the extreme left of the table

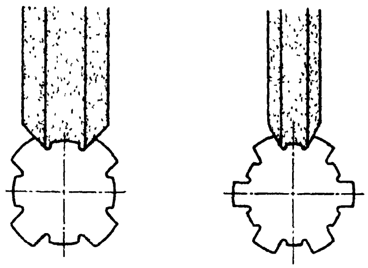

FIG. 10.—SINGLE-WHEEL METHOD OF SPLINE-SHAFT GRINDING

Using one wheel which is trued to the shape of the spline with a diamond.

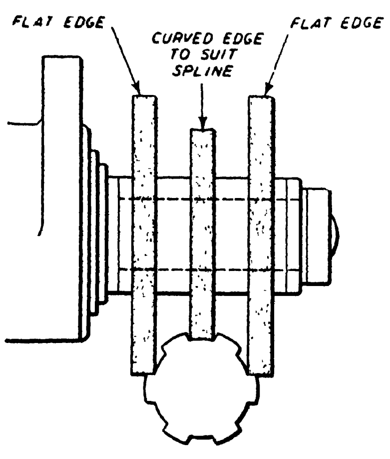

FIG. 11.—THE THREE-WHEEL METHOD OF SPLINE-SHAFT GRINDING

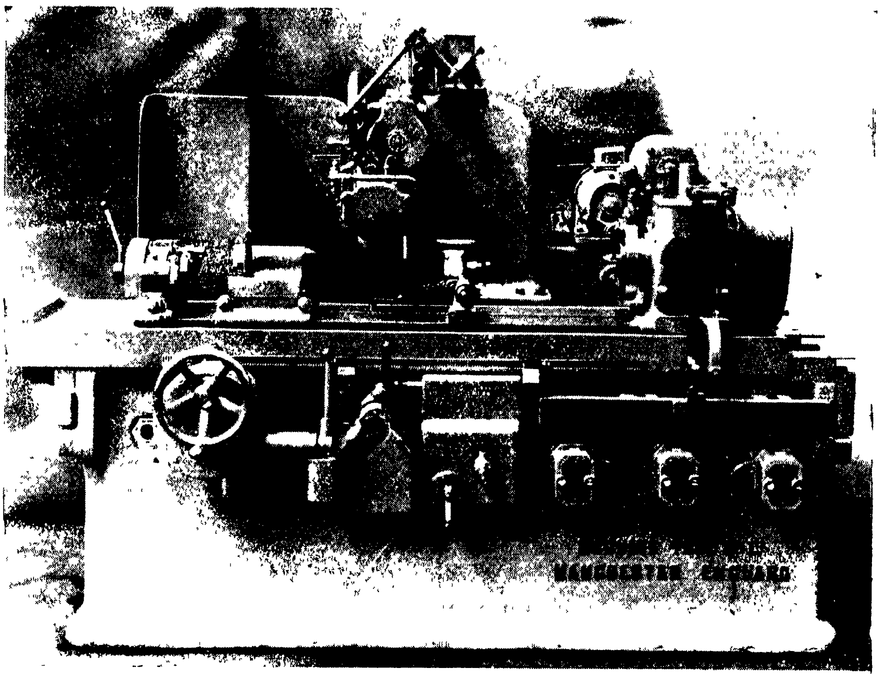

FIG. 12.—CHURCHILL SPLINE-SHAFT GRINDING MACHINE

(Fig. 12), fitted with three diamonds, which enables the shafts to be ground to an accuracy of ± 0·0004 in.

Fig. 13 gives some idea of the use of this triple-diamond tool.

The diamonds are set in their positions by a master gauge, shaped to suit the spline, and the whole device is set to the correct height in relation to the shaft. By operating the lever visible at the rear, the two outside diamonds move in a straight line, at an angle, to face the sides of the wheel, whilst the centre diamond describes an arc, to radius the wheel face. Naturally, the wheel head will have to be lowered a little farther each time the wheel is trued, but this does not affect the accuracy of the setting.

The height of the truing device is always the same, which means that the height of the trued wheel face will always be the same.

The production speeds of these machines are very high, and a six-splined shaft, 2 in. diameter by 10¼ in. length, can be ground to limits of $\frac{4}{10000}$ in. in six minutes. This represents an important advance, when compared with the method of hand-honing formerly used.

THREAD-GRINDING MACHINES

Special machines are now manufactured to grind the threads for screw gauges, taps, dies, gear hobs, and similar articles, which must be accurate to

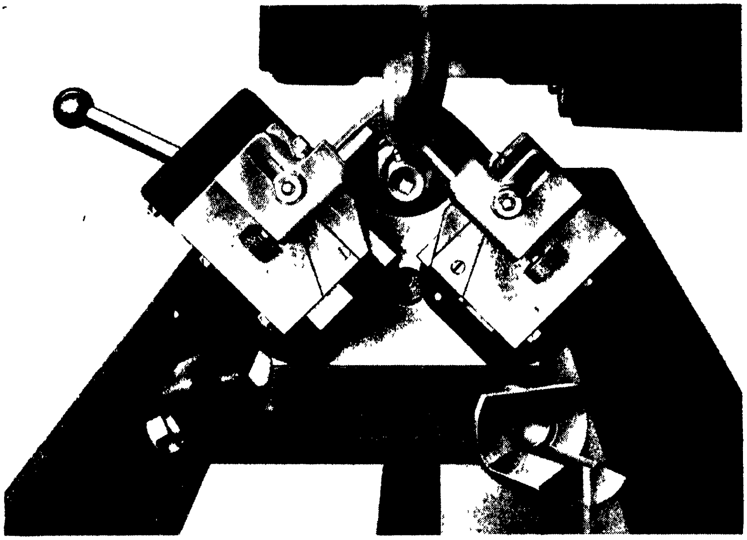

FIG. 13.—TRIPLE-DIAMOND TOOL FOR DRESSING WHEELS USED FOR SPLINE-SHAFT GRINDING
(*Churchill Machine Tool Co., Ltd.*)

within a few ten-thousandths parts of an inch. When examined under a microscope, it will be noticed that these threads are composed of definite curves which must be very accurately copied, in order that the nuts and bolts made from the taps and dies will fit each other.

A machine very similar in appearance and operation to the ordinary cylindrical grinder is used for threading these articles, but it is provided with a special wheel with grooves, corresponding to the threads, cut into the face. In order to grind the corresponding threads into the article, it is necessary that the table should move along at the same rate as the pitch of the thread, as when screw-cutting in a lathe, this being done either by using a train of gears to obtain the correct movement (as in screw-cutting) or by fitting a special shaft which has a thread cut on it to suit the lead of the thread being ground.

When the table is set to move at the correct speed, it is then only necessary to feed the work up to the wheel and start the automatic table movement. As the wheel reaches the end of the thread, it automatically moves away from the work so that the table can return to the starting position in readiness for another grinding cut. Some machines are fitted with a microscope so that the thread can be easily examined. Two different methods are used to "true up" the grooved wheel, one consisting of a diamond which can be moved over the wheel at the correct pitch, and the other of a hard steel wheel grooved exactly the same as the grinding wheel, which is pressed on to the latter, thus reforming the serrations.

CENTRELESS GRINDING

The introduction of centreless grinding has revolutionised production on certain classes of work. Until recently, in order to grind any cylindrical article, such as a pin, it was necessary to hold the work either between centres or in a chuck. With centreless grinding, however, it is not necessary to hold the article in any way, but merely to pass it between two wheels; a support or rest fixed between them prevents the work from dropping too far down and causing damage (see Fig. 14).

The grinding wheel revolves at high speed, whilst the control wheel revolves comparatively slowly, thus giving a turning movement to the work. By correctly setting the relationship between the wheels, it is only necessary to pass the work between them, and it emerges from the other side ground to the correct size.

TABLE OF GRINDING ALLOWANCES
(Suitable for ordinary conditions)

Diameter of work (in.)	*Length of work (in.)* 3	15	30	48
½	0·010	0·015	0·020	0·020
1	0·010	0·015	0·020	0·020
1½	0·010	0·015	0·020	0·020
2	0·015	0·015	0·020	0·020
2½	0·015	0·020	0·020	0·025
3	0·015	0·020	0·025	0·025
4	0·020	0·020	0·025	0·025
5	0·020	0·025	0·025	0·030
6	0·020	0·025	0·030	0·030

SPEED TABLES

Diameter of wheel	4,000 *ft.*	4,500 *ft.*	5,000 *ft.*	5,500 *ft.*	6,000 *ft.*	9,000 *ft.*
in.	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*
1	15,279	17,189	19,099	21,008	22,918	34,377
2	7,639	8,594	9,549	10,504	11,459	17,189
3	5,093	5,729	6,366	7,003	7,639	11,459
4	3,820	4,297	4,775	5,252	5,729	8,594
5	3,056	3,438	3,820	4,202	4,584	6,875
6	2,546	2,865	3,183	3,501	3,820	5,729
7	2,183	2,455	2,728	3,001	3,274	4,911
8	1,910	2,148	2,387	2,626	2,865	4,297

SPEED TABLES—*continued*

Diameter of wheel	4,000 *ft.*	4,500 *ft.*	5,000 *ft.*	5,500 *ft.*	6,000 *ft.*	9,000 *ft.*
in.	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*
10	1,528	1,719	1,910	2,101	2,292	3,439
12	1,273	1,432	1,591	1,751	1,910	2,865
14	1,091	1,228	1,364	1,500	1,637	2,455
16	955	1,074	1,194	1,313	1,432	2,148
18	849	955	1,061	1,167	1,273	1,910
20	764	859	955	1,050	1,146	1,719
22	694	781	868	955	1,042	1,563
24	637	716	796	875	955	1,432
26	588	661	734	808	881	1,322
28	546	614	682	750	818	1,228
30	509	573	637	700	764	1,146
32	477	537	597	656	716	1,074
34	449	505	562	618	674	1,011
36	424	477	530	583	637	955
38	402	452	503	553	603	905
40	382	430	477	525	573	859

(*By courtesy of Universal Grinding Wheel Co., Ltd.*

RULE: TO CALCULATE SURFACE SPEED IN FEET PER MINUTE

SPEED = (Diameter of wheel in inches) × (0·2618) × (rev. per min.)—

Also

$$\text{Rev. per min.} = \left(\frac{\textit{Surface speed in feet per minute}}{\text{Wheel diameter in inches} \times (0{\cdot}2618)}\right)$$

Methods of Feeding the Work

This method is known as "through-feed" grinding, from the fact that the work is passed completely through the wheels. As can be seen, this method is only suitable for parallel work which is the same diameter throughout its entire length.

Another method of feeding the work is "in-feed" centreless grinding. This is limited to surfaces not longer than the width of the grinding wheel, although tapered and spherical work can be ground, as well as that which is parallel, by the use of specially shaped wheels.

The work does not pass through the wheels, but revolves in a fixed position, the wheels closing together until the correct diameter is obtained, when the movement is automatically reversed and the work ejected. This method of grinding by feeding into the work without side movement of the table is known as "plunge cut" grinding.

Concentric grinding is a variation of the "in-feed" method used for work with a hole or bore through the centre, where it is important for the hole and outside diameter to be absolutely concentric. Instead of the work resting on the usual blade type of support it is held on a rod or arbor passed through the hole. Thus, as the work revolves on the arbor, the outside diameter is ground absolutely concentric when the wheels feed together. Cast-iron bushes, 2¼ in. long and 2 in. in diameter, can be ground by this method to within limits of 0·0004 in. ($\frac{4}{10000}$ in.) for concentricity at the rate of 120 per hour.

All sizes on various types of centreless grinders are obtained automatically by previously set stops, compensation for wear of the grinding wheel being also automatically provided; this measurement is not required once the machine is "set."

Advantages of Centreless Grinding

With the "through-feed" method, the operation is practically continuous. The work is normally rigidly supported throughout the grinding operation with both the "through-feed" and "in-feed" methods. As no centres are employed, there is no axial thrust; therefore the operator can deal with long brittle articles as well as articles of very slender design. The lack of centres means no distortion, due to elongation by frictional heat generated between centres whilst grinding, or to the work being pushed against the thrust of the centres. Consequently, grinding allowances are reduced and the grinding-wheel surface requires less maintenance.

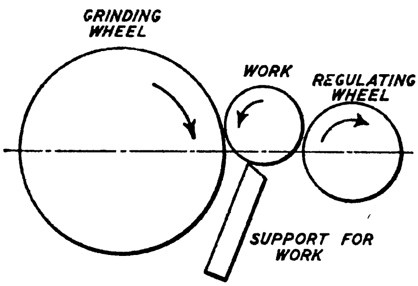

FIG. 14.—ACTION OF A CENTRELESS GRINDING MACHINE

The angle and height of the work support varies according to the nature of the work which is to be ground.

Principles of Centreless Grinding

There are three factors in the system: the grinding wheel, the control wheel, and the work rest. Both grinding and control wheels are generally abrasive wheels, but for quite a number of reasons, dealt with later on, the control wheel may be of steel or some suitable material. The work rest lies between the two wheels, and is so disposed that it maintains the work being ground above the common centre of the wheels, or below the common centre, according to the nature of the work. At times the grinding wheel is in cup form, with the axis practically at right angles to the job. It will be seen that there appears to be no limit to the application of centreless grinding.

Difference between Centre and Centreless Grinding

On the centre grinder the line between the two centres forms the centre of revolution and, providing there is no distortion due to wheel pressure or elongation due to friction heat, a true cylinder is formed. With centreless grinding the work revolves about its own periphery, thus providing its own axis of revolution. Centres limit the length, whereas with centreless grinding, the various pieces can be fed into the machine one after another without the slightest effort. Many machines are fitted with automatic feeding and ejecting apparatus.

Grinding Action

The principle of this method of grinding is set out in Fig. 16. It will be seen that the centre line is common to the wheels and the work. The exaggerated irregularity on the work pushes it towards the grinding wheel, and as it revolves

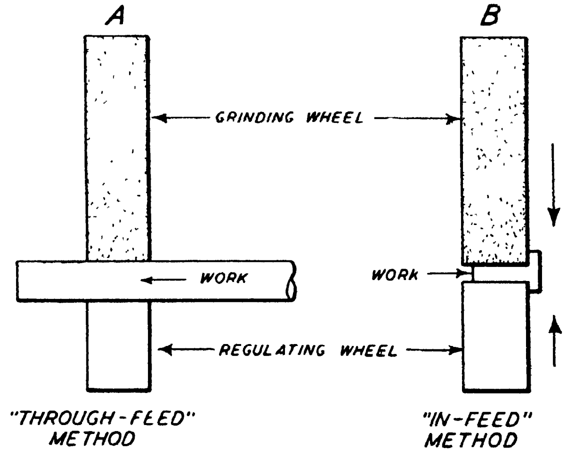

FIG. 15.—"THROUGH-FEED" AND "IN-FEED" METHODS OF CENTRELESS GRINDING

Note that in the "through-feed" method the wheels are set at a fixed distance apart and the work passes through them, but for the "in-feed" method the work cannot pass through the wheels because of its shape, so it rotates in the position illustrated and the two wheels close together until the correct size is obtained.

theoretically rounds up until the high spots are eliminated. In practice, however, this layout, although the high spot causes a depression immediately opposite itself, does not guarantee the work will be truly cylindrical. The compensation due to the high spot pushing the work over to the grinding wheel does produce work of a uniformly constant diameter, but, nevertheless, it may not be a true cylinder.

If the work centre is lifted, as in Fig. 17, still using a flat-top work rest, the control wheel pushes over the work towards the grinding wheel, but the depression is not formed immediately opposite the high spot. Also, as the high spots come into contact with the control wheel, they tend to raise the location of the work centre so that a larger diameter is, for the moment, being generated. The more pronounced the high spot, the larger the tendency for the work

diameter correspondingly to increase. The result is that only the tops of the high spots are ground off, and at each revolution of the work the high spots grow smaller. As the work of grinding proceeds, the high and low spots, not being diametrically opposed and always diminishing in size, gradually cancel one another out until the true cylinder is produced.

Up to now we have dealt with the subject from a theoretical point of view only, but in practice, as is often the case, some further alteration is found necessary. Fig. 18 shows the same arrangement of wheels, but a sloping work rest. Hitherto the work rest has raised the work farther above its normal centre and at a greater distance between grinding and control wheels, but with the sloping work rest, part of the weight of the job will be carried by the control wheel, resulting in an increased pressure between the job and the control wheel, ultimately increasing the rotating speed of the job. The sloping work rest increases the speed

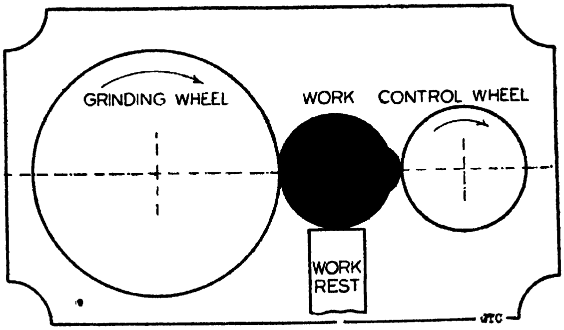

FIG. 16.—PRINCIPLE OF CENTRELESS GRINDING

With the centre line common to both wheels, the work will not result in a true cylinder.

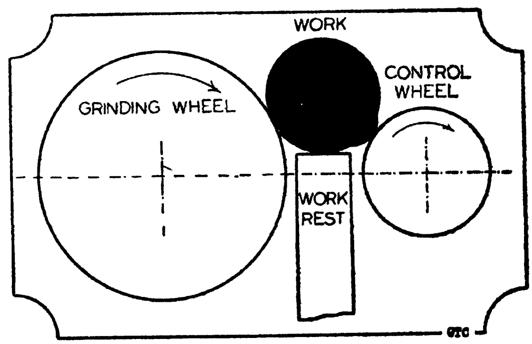

FIG. 17.—PRINCIPLE OF CENTRELESS GRINDING

By lifting the work rest as shown, a true cylinder can be produced.

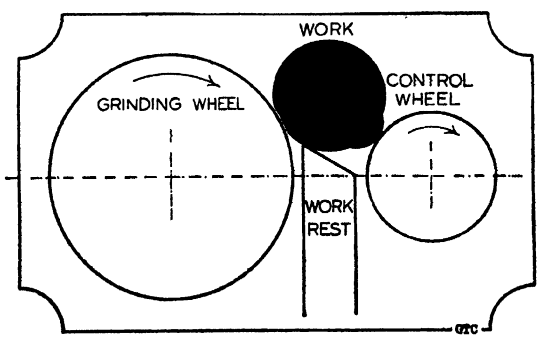

FIG. 18.—PRINCIPLE OF CENTRELESS GRINDING

By using a sloping work rest, the work is rounded up without taking off as much metal as in Fig. 17.

of the rounding up, and the job becomes a true cylinder at a larger diameter than it would have been had the flat-topped work rest been used.

Grinding- and Control-wheel Speeds

It will be noted that operating point on the grinding wheel runs in the opposite direction to the corresponding point on the control wheel. The grinding wheel runs between 5,000 and 6,000 surface feet per minute, the ordinary practice in grinding, but provision is made to run the control wheel at anything between 50 to 250 surface feet per minute, the selection depending on degree of finish, the amount of stock to be removed, and the actual diameter of the work. With large-work diameters, low control-wheel speeds are desirable on account of the area of contact with the grinding wheel. Naturally, slow control-wheel speed is necessary for final passes when fine finish is imperative.

It appears somewhat mysterious, on account of both grinding and control wheels driving the work in the same direction, that the work does not revolve faster, but in actual practice the speed of the work is definitely governed by the speed of the control wheel. The work is longer in contact with the control, therefore adhesion is greater.

Through-feed Methods

Through feed is obtained by inclining the control wheel so as to draw in the material to be ground between the grinding wheel and the control wheel. The angle of inclination governs the speed at which the work will pass between the wheels, and only straight cylindrical work can be passed. Normally, machines made for through grinding are arranged for a maximum inclination of 10°. Fig. 19 shows the method, also the formula to determine the speed which the work will pass through the grinder. The error is not more than 2 per cent. With formed grinding wheels, it is often an advantage to set the control wheel very slightly to keep the job against a projecting shoulder on the grinding wheel. The actual work will then be in-fed, but the inclination prohibits any reciprocation of the work.

In-feed Methods

When loading the machine, either the control or grinding wheel is withdrawn, the position of the job in relation to the grinding wheel being governed by a stop at the side of the wheel, against which the work will rest. With the work in place, the grinding wheel (or the control wheel, according to the make of the machine) is advanced to the desired position until the required dimension is attained. The grinding wheel, or wheels, can be formed to any shape, but the grinding wheel or wheels must be of such a width as to cover the complete length of the surface to be ground, whereas this is not so with the through-feed method. This system is somewhat on the same principle as with centre-grinding machines, and two or three wheels on a common spindle can be used where work of different dimensions and with shoulders is to be ground. Taper grinding, spherical grinding, and other irregular work can be executed. As already

mentioned, the control wheel can be set over very slightly (about half a degree perhaps) to assure the work pressing against the shoulder. With cylindrical work an oscillating movement of the grinding wheel produces a finer finish and the oscillations of the wheel have no effect on lateral movement of the work, the control wheel maintaining full control all the time.

End-feed Method

This method is mainly used for taper work, the wheels and work rest being set at predetermined positions. A stop is arranged to arrest the job when it has been drawn in sufficiently far as to be the correct size.

Advantages of the Through-feed Grinding

In repetition work, job after job can be rapidly passed through the machine without resetting, nor has the operator to waste time through inserting the work between centres. The lengths of the work can be anything from a fraction to 20 ft. in length, whilst diameters can be down to 0·012 in. and up to 4 in. and even larger.

Advantages of In-feed Method

Stepped, formed, taper, and spherical grinding is well within the range of the centreless machine. There is no necessity for the unground portion of the work to have the same axis as the ground portion. Work with two or more diameters is bound to have the same concentricity, whilst, by the aid of attachments, many unbalanced jobs can be done with ease.

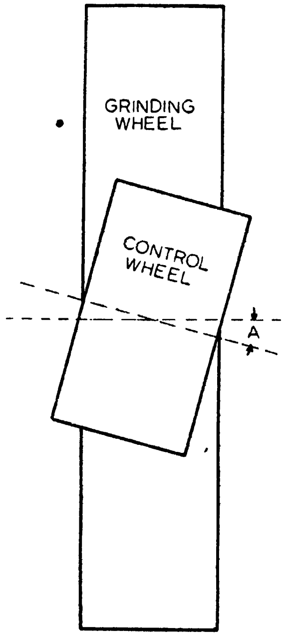

FIG. 19. — THROUGH-FEED GRINDING DATA

If D = Diameter of control wheel in inches and A = angle of inclination of control wheel, then the feed may be calculated thus:—

Feed (in inches per min.) $= D \times 3{\cdot}1416 \times \sin A$.

Wheel Truing

The grinding wheel has to be trued up more frequently than the control wheel, but truing is less on centreless machines than others, although the frequency itself cannot be given on account of the nature of the materials and the sum of the stock removed at a time. It is certain that heavy cuts will need more applications of the diamond than light cuts, specially on account of the wearing away of the edge of the wheel, due to that part of the wheel having to do an excessive amount of work.

The control-wheel truing device must, on account of the many inclinations of the control wheel itself, give the face of the wheel a concave surface, so that it engages with the work to its full extent. The device should have an

arrangement of both coarse and fine feeds, also arranged for angular adjustment to meet the requirements of the control wheel. In some cases the necessity to agree with the angular position of the control is obviated if the diamond is set to follow a path parallel with the line of contact between the work and the wheel.

A common device for the truing of both wheels is fitted to Scrivener centreless grinders, illustrated in Fig. 20. The swinging arm *A* may be lowered between the wheels and then clamped by the lever *B*. The stop *C* is adjusted so that when the arm is lowered the diamond *D* for truing the control wheel is at the same height as the line of contact between the wheel and the work. Two diamonds are employed, one for each wheel, the required diamond being brought into the operating position according to which wheel is to be trued by traversing the cross-slide by means of the handwheel *F*. The longitudinal slide is traversed by the handwheel *H* to move the diamond across the face of the wheel. The fact that the diamond engages the control wheel along the work contact line means that a correct profile is ensured, whatever the angle.

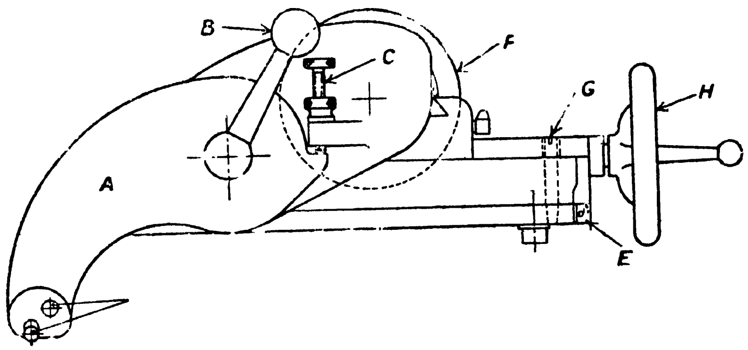

FIG. 20.—ARRANGEMENT OF WHEEL-TRUING DEVICE ON SCRIVENER MACHINE

Taper Truing of Scrivener Machines

For taper truing the longitudinal guide is adjustable up to 12° in either direction, setting being facilitated by the scale at *E*. The dowel *G*, which locates the guide in the zero position, is removed to permit this adjustment.

Work Rests

As the upper side of the work rest is in continuous contact with the revolving series of jobs passing along it, the conditions are somewhat severe. Whatever the blade material, the wearing surface must be ground dead true. In one example a separate rod of hardened steel or stellite can be turned by means of a square on the end to offer another face. In this manner the wear of the blade itself is eliminated.

The width of blades is determined by the location of the grinding and control wheels, but it should be as large as possible to maintain rigidity. For the

majority of grinding operations blades have an angular-top edge, but for long bar work, flat and V-blades are advocated. With small diameter and the consequent smallness of the work rest and where wide wheels are used, there is a tendency for deflection; therefore the generally adopted angle of 30° of the work rest must be modified to suit the case.

Automatic Ejection of Work from In-feeding Machines

On in-feeding machines there is no necessity for lateral guides, but provision must be made to determine the correct position of the work to be ground. This generally takes the form of an end stop, and is mostly located at the rear of the grinding throat; it also acts as an ejector. When the control wheel has been withdrawn, a hand lever advances the end stop and ejects the finished work. The ejector spindle must be smaller than the work itself. The hand ejector imposes extra duty on the operator and delays the work procedure; therefore it is desirable to have some system of automatic action. The method adopted by the Scrivener machine is a good guide to safe and certain ejection. Fig. 21 shows how this is effected. The lever *A* governs the movement of the control-wheel slide, and as it is moved to the right to withdraw the control wheel at the conclusion of the grinding operation (the opening of control wheels is generally in the neighbourhood of 0·04 in.), the trip peg *C* moves the detent lever *D*. The latter actuates the ejector lever *F* through a shaft and linkage, the head of the lever being caused to strike the end of the ejector rod *G* and force it forward. Further movement of the peg *C* releases the detent lever *D*, which is immediately returned by the spring *H* on the ejector rod. The detent lever is divided, the heel of the front portion being supported by an adjusting screw *E*, which permits of the length of the stroke of the ejector rod being varied from 0 in. to 4 in. without any alteration of the setting of the nose *B*. Provision is also made for

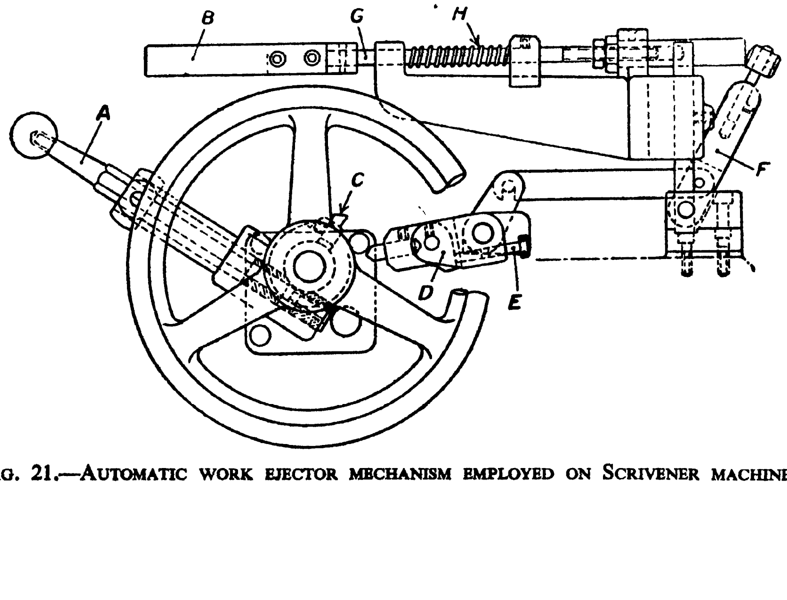

FIG. 21.—AUTOMATIC WORK EJECTOR MECHANISM EMPLOYED ON SCRIVENER MACHINES

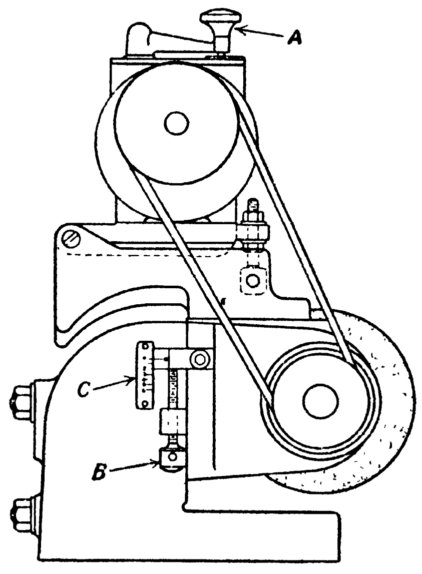

FIG. 22.—ARRANGEMENT OF CONTROL-WHEEL DRIVE ON SCRIVENER MACHINE

accurate adjustment of the rod *G* in order that the work may be held in the required position during the grinding operation. This is accomplished by turning a screwed sleeve, and the setting is retained by a locknut.

Fixed-head Machines — Method of Control

As the name implies the head is fixed; therefore all adjustments are made on the control-wheel head. The fixture securing the grinding wheel is generally cast integral with the bed of the machine. Adjustment of the control wheel for through-feed is generally by means of a large head wheel. Adjustments can be made to 0·0001 in. (ten-thousandths of an inch).

The control wheel must be mounted with the same rigidity as the grinding wheel. Both must run dead true and without vibration. The situation is difficult and complicated, because the control wheel has to be continuously adjusted, moved on its slide, and set at the desired angles. The example shown in Fig. 22 is of a self-contained arrangement employed on Scrivener machines. The motor is carried on the top of the wheel head and drives the spindle through a two-speed gearbox and three-step V-belt pulleys. The normal working speed of the control wheel is too slow to permit satisfactory truing, and the gearbox provides a ready means of increasing the speed when necessary, the change being effected by the lever *A*. Angular adjustment of the control-wheel spindle is obtained by swinging the complete head and motor unit about a spigot, the axis of which intersects that of the control-wheel spindle at the mid-point of the wheel's thickness. Accurate angular setting is obtained by turning the screw *B*, a graduated scale being provided at *C*. After the head has been set to the required angle, it is clamped to the vertical face on the slide.

The fixed head of this same machine is shown in Fig. 23, the front-end bearing being carried in opposed taper roller bearings, the inner and outer races being separated by suitable spacing pieces. The inner races of the bearing are locked up solid with the spindle by means of nuts *B*, while the outer races are secured by the end cover of the housing. The bearings are initially adjusted to eliminate all play. The rear end of the spindle is carried on a roller bearing *C*, which is arranged to float, and thus accommodates any variation in the length of the spindle due to fluctuations in temperature. In order to prevent the forma-

tion of chatter marks on the work, a lightly spring-loaded damper *D* is arranged to bear on the spacing piece between the inner taper races. This exerts a constant restraining pressure, and thus serves to damp out vibration.

Many machine makers use plain bearings for their machines, but all use the electric motor as a drive.

Grinding Methods

In grinding long bars of small diameter, they are generally passed through the machine below centre. The bars may be black, but it is essential that they are straight. The grinder cannot be used for this purpose on any account. Bars of small diameter are generally flexible enough to spring under the pressure of the grinding and control wheels, but the machine cannot deal with kinks of any description. Irregularities are removed in the usual way, and with *very* small diameters there is certainly a permissible degree of straightening, owing to the flexibility of the material due to diameter, but it is unfair to rely on the machine to carry out work for which it is not intended. The guides for the bars, both before grinding and after, should be of such a length that overhang, which tends to raise the portion on the machine, is definitely eliminated. Long bars as small as $\frac{1}{32}$ in. can be ground with speed and ease.

Non-metallic materials can also be ground, the lubricant suggested being water. After passing through the machine the water is discarded, owing to dust. The rate of production on steel bars is governed by the stock to be removed and the desired finish. With a tolerance of 0·001 in. the stock to be removed should not exceed 0·015 in., otherwise the cost increases. With thin tubes it must be remembered that only light cuts can be taken. It is quite possible, however, to grind to within 0·0005 in. with a very slight increase in cost.

Multiple In-feed Grinding

With all in-feed grinding, the part to be ground must not exceed the length of the face of the wheel. The work is maintained in correct position by the aid of a stop and the slight inclination of the control wheel as already explained. Whatever the actual method of feeding either of the wheels inward, the machine should be designed so that on reaching the stop the wheel can be no further advanced and undersize the work. Most stops are very finely graduated, so that accuracy to 0·0001 in. can be attained.

Stepped parts are mainly produced on in-feed machines, such as bolts, headed spindles, shackle pins, internal-combustion engine tappets, armature shafts for small dynamos and motors, also set pins of two or more diameters, etc. The work generally passes through the machine twice and within 0·0005 in. for size. The total stock removed in the two cuts is about 0·015 in. According to design, work can be turned out from 150 to 300 pieces per hour. With an in-feeding machine the work rest is often raised during the operation of removal of the part, returning to its original position before the next grind.

Relief-skirted aluminium-alloy pistons are frequently ground by fitting a steel expander within the piston during the grinding process, the removal of the

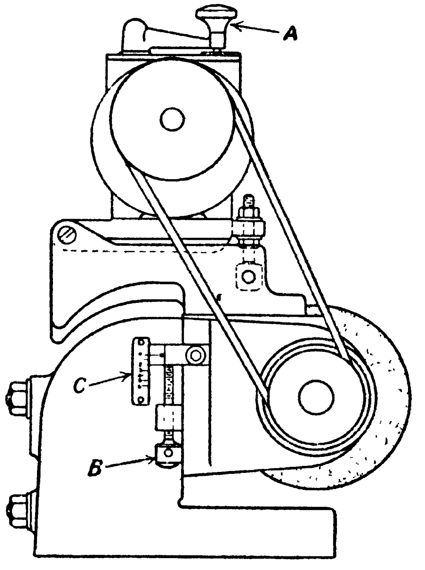

FIG. 22.—ARRANGEMENT OF CONTROL-WHEEL DRIVE ON SCRIVENER MACHINE

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FINE GRINDING AND FINISHING OF STEEL

1.—HONING

AN abrasive wheel-grinding operation, while it will give a fine finish in many instances, and such a finish may be adequate to the needs of the industry or manufacturer concerned, cannot give the more refined precision finishes that are often required, and for this purpose specific types of extremely fine grinding operations are employed. There are three of these, namely, honing, lapping, and super-finishing. The essential thing is that the reader should not confuse them. This section deals with honing, and subsequent sections deal with lapping and fine finishing. The general outline of a honing operation is shown in Fig. 1.

Honing was originally designed for internal work, because normally external work can be brought to a finished dimension by cylindrical grinding. (There are certain exceptions, such as those where a straight parallel line effect is required, as in recuperator pistons, which cannot be obtained by other methods.) It both completes the bringing of the work to its final dimension and produces the desired degree of mirror finish of the surface. It is not the same as internal grinding with the abrasive wheel, the difference being that in grinding the wheel used has a small area of surface contact, whereas in honing there is a much larger area of contact, the stones being from extremely small lengths up to 8 in. long (and even longer if required) by $\frac{1}{4}$–$\frac{5}{8}$ in. wide.

Honing is more economical owing to the liability of internal grinding wheels to chatter on small bores, and the longer time taken, unless highly specialised equipment is employed, while the wheels have line contact, whereas the hone has flat contact. Moreover, honing is sometimes employed for cylindrical work, which it finishes on the external surface, but these instances are relatively few, and the main advantage is that the work is carried out at an extremely rapid rate. We shall deal with this point later.

Principles of Honing

In honing, the abrading tools or *stones* are of flat, rectangular form, are revolved at an average speed of 120 ft. per minute, and have at the same time a longitudinal traversing motion. This makes them travel in a widely angled helical path, preferably 45°. The honing marks are longer and more criss-cross than in ordinary internal grinding. The hones are generally not longer than 50 per cent.

of the internal diameter they are to work upon. A coolant is normally employed, paraffin being the most suitable. The abrasive used is from 36 to 180 for rough honing and from 300 to 600 for final honing.

The speed used should develop no frictional heat, the object being to obtain free, cool cutting without rubbing. Then the hones present to the work a surface travelling forward, and so achieve a helical motion and an individual type of finish of which criss-cross lines, as indicated, are the characteristic feature. These are produced by the great length of the traverse—sometimes as much as 50 ft., while for extremely long guns 96 ft. is not unknown—and by the revolution of the hones. The swarf is held by the face of the hones, and forced in front

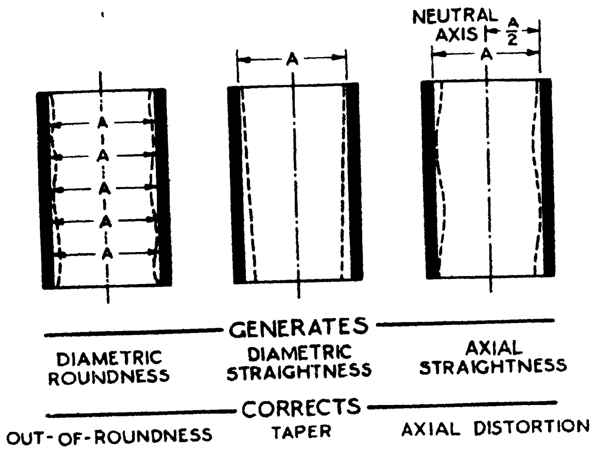

FIG. 1.—THE HONING PROCESS

of them, so that it is not cleared till the direction of movement is reversed. In other words, the stones clean themselves.

The hone itself is composed of a number of abrasive stones or sticks, as shown in Fig. 2, presenting a comparatively large superficial area, and each consisting of a fine-grained abrasive material carefully bonded. From three to eighteen or twenty-four of these stones are arranged in their holders along the internal circumference of the work, and are set at equal distances from each other, then made to revolve and traverse with a reciprocating motion in the bore or hole. The point to note is that whereas in ordinary grinding only two motions are used, in honing there are three, the backward and forward and the rotating motions.

The stones themselves are carried in shoes (or holders) having controlled radial movement (i.e. movement from a common centre). They are fixed to the machine spindle, their longer axes parallel to it, their shorter axes radial.

Accuracy of Honing

Honing is mainly employed for fine finishing of the bores of automobile and aircraft engine cylinders, Diesel engine sleeves, and petrol engines of all types, small compressors for refrigeration, etc., ball bearings, taper bearings, and bearings of particularly high quality and fine finish. It is specially advantageous when length of service and working efficiency are primary needs.

Machining operations and grinding carried out with the abrasive wheel leave behind "hills and valleys" on the surface, constituting the high and low ridges of the metal. These may be obscured to some extent by the flowing of a skin of metal over them as a result of frictional heat and pressure combined. Consequently, the finish looks good, but when the piece is put to work, and has to withstand severe stresses or prolonged service wear, this false surface crumbles or spalls, and the clearances then become inaccurate. Honing removes the false "flowed" surface, and at the same time gives a sound and mirror-like finish combined with great accuracy.

By means of the hone it is possible to obtain work finished to $\pm$ 0·0001 in. on diameter, while it is equally precision-honed as regards circularity and straightness. Usually a rough honing is given first, which brings the diameter down to within 0·0005 in. or 0·001 in. of the final dimension, after which a final honing soon brings the surface to the desired degree of accuracy. At the same time honing is not limited to this range, and indeed is from 0·0001 in. on the smallest bores to 0·001 in. on bores of very large diameter (e.g. 3 ft. 6 in.).

It should be noted that honing can be used as a means of rectifying dimensional errors left by previous machining or grinding operations, but it cannot, unless special methods are used, correct misalignment of the bore itself. This is because the hone has a degree of universal movement in relation to its driving agent, and must therefore follow the bore as it finds it. Only by giving the work axial movement and keeping the hone rigidly in a vertical plane is it possible to realign a hole, and even then the work must be small.

The Hones

Honing sticks are of different thickness, breadth, and length, and how many of them are used for a given job is governed entirely by the diameter of the hole in which they are to work. The table below gives a rough guide to the number of stones for each diameter.

Diameter of Hole in inches	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	3	4	6	8	12	24	36
No. of Stones .	2	2	2	3	4	5	5	6	6–10	6–10	6–10	9–12	9–12	12–18

The type of holder used varies mainly with the rate of output required. Where the maximum rate is essential, the stones are affixed by a suitable cement to holders made of sheet metal or hardened steel. Where there is no need for

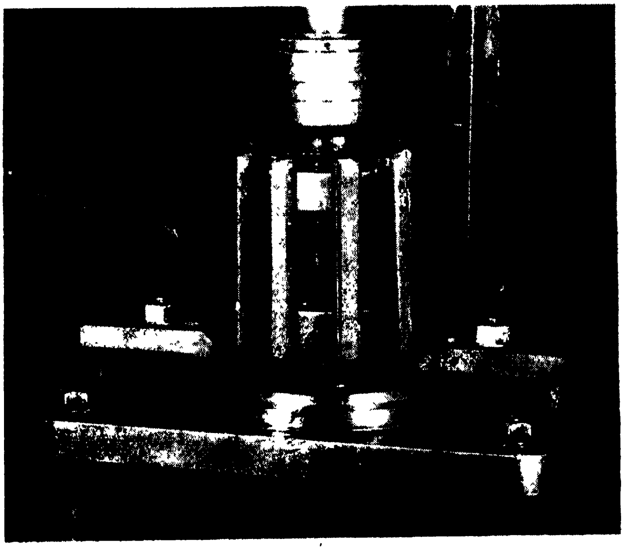

FIG. 2.—HONING OIL-ENGINE CYLINDER-BLOCK SLEEVES WITH AN ADJUSTABLE MULTI-STONE HONE (*The Daimler Co., Ltd.*)

specially large output in a given period, or the bores are of considerable diameter, the stones can be either clamped in position or cemented into holders, or both.

Hones are made on the expanding principle to compensate for enlargement of the bore in the course of the honing operation, thus enabling the proper pressure to be maintained on the work surface. Various methods of expansion are available, all of which are familiar to most engineers and need not be detailed here. The brake or hydraulic, the cam, and the spring, are some of the devices used.

Speed of Honing

There are two speeds to be borne in mind in honing, that of the hone itself and that of the traverse. The governing factors are the type of steel being honed, the quantity of metal to be eliminated, the diameter of the bore, and the type of surface finish required. As compared to grinding with an abrasive wheel, these speeds are lower. The speed of the hone spindle ranges, for steel, from 70 to 150 surface feet per minute, increasing in proportion as the work becomes smaller. The speed of the traversing stroke for steel should be about 40 lineal feet per minute. The number of reciprocating strokes required depends entirely on the length of the stroke: 100 strokes a minute is about the average for a 5-in. stroke.

Pressures in Honing

Honing pressure depends on the class of work, being greater for holes of small diameter than for those of large diameter. It is also affected to some extent

by the type of steel being honed, and the character of the bond used to hold the abrasive particles. On the whole, unit honing pressures are much lighter than grinding pressures.

It should be noted that in honing steel that has been hardened, the pressure should be heavier in proportion, though the amount of material to be removed in a given time is less. This may appear paradoxical, but to explain the reasons would involve the reader in complicated metallurgical discussions which are beyond the scope of this article. Briefly, it may be remarked that there is evidence of a connection between the respective *cutting resistances* (i.e. resistance to cutting stresses) of the bond and the steel.

As a rough guide, it may be said that the first stage of honing is carried out at pressures ranging from 30 to 70 lb. per square inch, and the second, or finishing, stage at pressures within the range 0–50 lb. per square inch.

Coolant

As stated, the most suitable coolants for work on hardened or high-tensile steel are paraffin or turpentine compounds, but their use is not confined to steel, and in addition to being used by themselves, they are also used as an ingredient in a number of proprietary coolants. For soft steel, the coolants mostly contain a lubricant such as lard oil. The function of a coolant in honing is to reduce the temperature of the work, flush away swarf, and prevent the stones from becoming charged with excess abrasive or particles of metal, and so injuring the work surface. A coolant also facilitates cutting.

Honing Machines

A machine for honing operations must above all things be rigid and powerful. Hydraulic operation is advantageous. Machines are either horizontal or vertical, the vertical, which resembles a drilling machine, being the more generally popular, the horizontal being specially advantageous for long internal holes. Multiple honing machines, in which as many as eight bores can be honed at one and the same time, have been designed. As the honing tool is self-centred in the hole at all times, the success of the operation is less affected than usual by the accuracy of the machine, as the hone is flexibly connected to the driving agent.

Honing Outer Surfaces

As earlier indicated, honing is not entirely confined to internal work. It is possible to hone the outer surfaces of cylindrical parts, but for this work a specially designed machine must be used. This is one of the instances in which it is the work that rotates and traverses backwards and forwards through the hone. The hone itself is made up of six or more stones held in a floating holder maintained firmly and immovably in the centre of the machine bed, and by virtue of this fact it is able to follow the contour of the work. It can be expanded

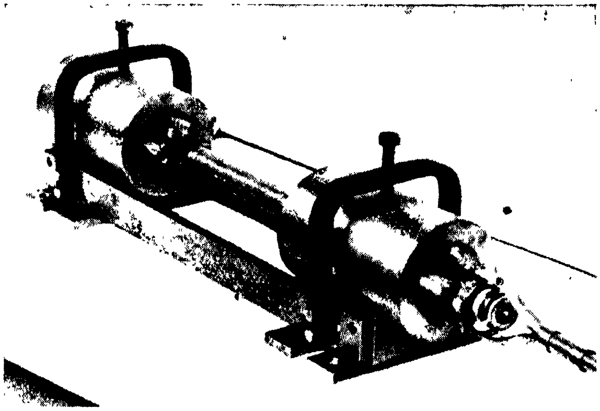

FIG. 3.—LINE HONE

The two heads carrying abrasive stones and guides are separated by a spacing bar of suitable length, and the hone is driven from a portable drill or by any convenient machine capable of rotary and reciprocating motion. (*Delapena and Son, Ltd.*)

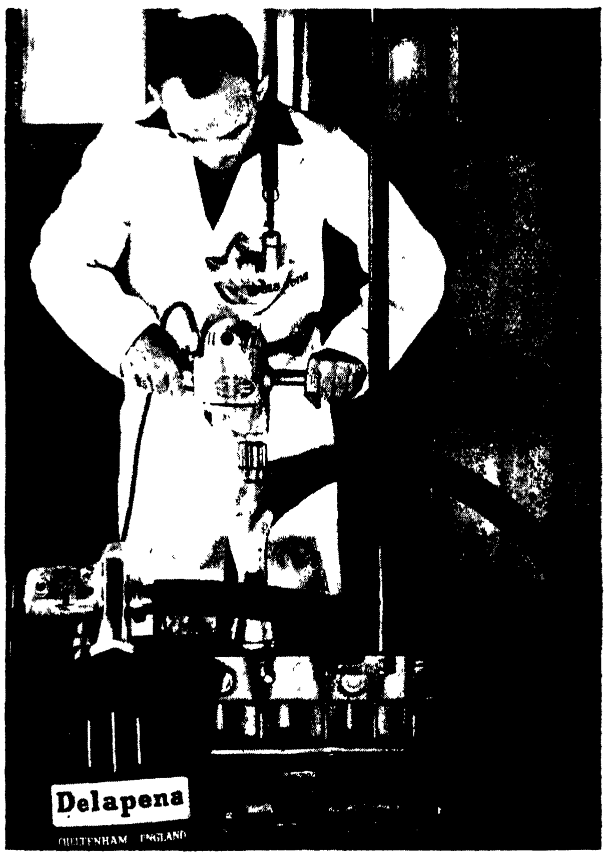

FIG. 4.—CYLINDER RECONDITIONING

With the equipment illustrated, cooling and the extraction of all dust, grit, and swarf as it is produced is achieved by means of the vacuum attachment. Diametrical and longitudinal accuracy of 0·0005 in. can be obtained and correct alignment between the centre lines of cylinder bores and crankshaft is maintained. (*Delapena and Son, Ltd.*)

as required, but once the stones have been refixed, they are firmly held. A different set of stones is used for the first stage of honing from that used for the finishing stage.

Allowances

The finish produced by the honing operation is not influenced by the immediately preceding operation, except that if too much metal is left on, honing to size will take considerably longer. In general, the allowance of metal left on is determined by the diameter of the bore, and on steel a good guide is 0·001–0·006 in. for bores from 1 in. to 6 in. diameter, 0·005–0·010 in. for bores from 6 in. to 12 in. diameter, and 0·005–0·020 in. for bores from 12 in. to 20 in. diameter.

There is no difficulty in honing bores with keyways or other openings cut in them, so long as the sticks or stones are able to span them.

Summing up, it may be remarked that the efficiency of the honing process depends to a great extent on the total number of cutting grains or *points* acting on a considerable area of contact. Thus, assuming an automobile cylinder to have a bore 3 in. diameter by 8 in. length, six honing sticks of 150 grit would, according to calculations, possess 140 times the area of abrasive, and as many as 98,000 cutting points at work, compared to 46 points at work in the purely line contact of an abrasive wheel. It is precisely the low unit stress resulting from the large area of contact that produces the mirror finish and the extreme precision, because the heat developed by one single grain has been calculated as 0·002 of 1 B.T.U. in rough honing compared to 4·6 for an abrasive wheel.

Miscellaneous Work

Blind holes can be honed if the finish of the stroke is carefully controlled and the hone allowed to dwell for a few seconds in the very end position of the bottom of the hole before the start of the usual stroke. For honing on horizontal machine-gun-barrels or other work in which the bore runs right through, the hone is usually guided at one end or both ends by pilots on the tool and bushes in the fixture.

Taper honing is now a practical possibility, and machines have been designed and are in use to produce taper bores where required.

The Diamond Hand Hone

Diamond abrasive is being used extensively for the final stage of polishing metallographic specimens because of its ability to polish very hard materials and constituents at a high speed, and without dislodgment of inclusions. It has now been established that the intermediate stages are carried out considerably more rapidly if a vitrified bonded diamond hand hone is used. This technique, it is claimed, enables high-speed steels of the high-carbon high-vanadium type to be quickly polished, as well as tungsten and other cemented carbides.

The diamond hand hone is of 600 grit, and $\frac{1}{4}$ in. $\times$ $\frac{7}{16}$ in. $\times$ 4 in., and is made by the Norton Co., Worcester, Mass. It is used with a 600-grit

silicon-carbide abrasive paste suspended in a light oil or paraffin. The paste is spread over a hardened-steel block ground dead flat. The hone is rubbed on the block to retain the diamond section flatness, and to dress it. Then the hone, with some of the paste adhering, is rubbed over the metallographic specimen. After a couple of minutes the coarse scratches are eliminated, and replaced by very fine scratches, which are removed by the final diamond polishing operation.

The function of the silicon carbide paste appears to be to maintain the keenness of the diamond hone by continuous dressing. The quality of the surface obtained is at least as good as that obtained by the normal methods, and is often much better. Pitting is greatly reduced. E. S.

Lapping and Superfinishing with Honing Machines

The honing process is one of the best of the metal-finishing processes, but there are two others that produce even finer surfaces, namely, lapping and superfinishing. With these we shall deal in the next two sections, and the reader is asked to pay careful attention to the differences that distinguish each process from the others.

First, however, we may mention that both lapping and superfinishing are frequently carried out on honing machines, following the normal honing operation. For lapping, the honing stones and holders are removed, and cast-iron or copper sticks are substituted after being suitably charged with a fine abrasive powder. Silicon carbide, aluminium oxide, chromic oxide or similar powders are used where fast cutting on hardened parts is required, whilst rouge or other polishing media are employed when high finish is the main requirement. In the latter case, hardwood blocks or fibre or leather strips may take the place of the cast-iron sticks and extremely fine finishes may be quickly produced in this manner. These are especially valuable on cylinders in which rubber or leather-packed pistons are used, as the life of the packing is greatly extended.

When lapping to remove minute dimensional errors following honing, the lapping sticks are expanded into the bore in the same manner as the hone, by means of the drivehead. This is shown above the hone in Fig. 5, the hone being shown here with the universal or driving coupling telescoped into the drivehead for access to the bore for gauging. Turning the knurled sleeve on the drivehead backwards, if desired, while running not only expands the stones or lapping sticks, but also controls their working pressure on the bore.

Where, however, the bore is already highly accurate and finish is the prime requisite, the cutting action may be somewhat too fierce with the ordinary drivehead and cone expansion. In such cases, the manufacturers of A-B Hones (Messrs. George H. Alexander Machinery, Ltd.) fit a spring washer behind one of the expansion cones to cushion the action, the strength of the spring being determined by the nature of the material to be lapped. In some cases the abrasive is circulated with the coolant and the leading edges of the lapping sticks are slightly rounded so that a self-charging action is obtained. It is, of

FIG. 5.—A-B HONE AND DRIVEHEAD, ADAPTABLE FOR LAPPING CYLINDER LINERS
(George H. Alexander Machinery, Ltd.)

silicon-carbide abrasive paste suspended in a light oil or paraffin. The paste is spread over a hardened-steel block ground dead flat. The hone is rubbed on the block to retain the diamond section flatness, and to dress it. Then the hone, with some of the paste adhering, is rubbed over the metallographic specimen. After a couple of minutes the coarse scratches are eliminated, and replaced by very fine scratches, which are removed by the final diamond polishing operation.

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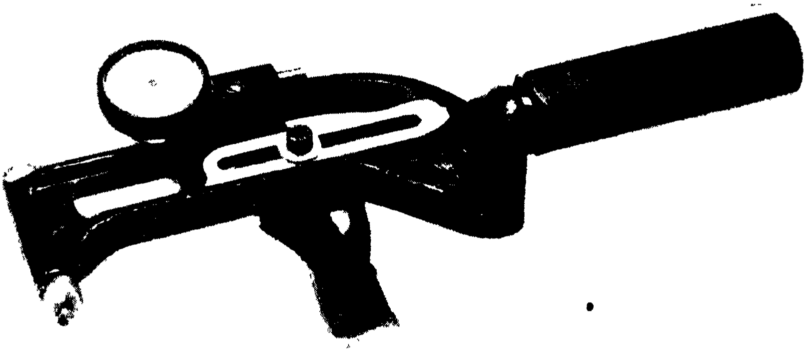

FIG. 7.—ADJUSTABLE GAUGE FOR CHECKING DIAMETER OF BORE WITHOUT REMOVING HONE
(*George H. Alexander Machinery, Ltd.*)

three or four diameters in length according to the wall thickness, but for longer tubes, a judicious use of adjustable jacks at intervals along the underside of the work is desirable.

Distortion of the work may also arise by the method of clamping. Preferably the enormous torque of a large hone should be resisted positively if possible by taking advantage of any projecting lugs or bolt holes in flanges, etc.; but where this is impossible, flexible steel straps lined with Ferodo should be used to hold the work in half-bearings or cradles similarly lined with friction material. Where the wall thickness is substantial, the simple and crude method shown in Fig. 6 is all that is required. This shows a 23-in. diameter hone operating on catapult cylinders approximately 33 ft. in length, removing up to 0·015 in. to a tolerance of 0·001 in. The illustration also shows how large-diameter hones are built up of interchangeable cast-steel spiders bolted and dowelled to a centre body for economy in covering a range of diameters with the minimum outlay. On the right may be seen the 7-in. diameter universal coupling capable of transmitting 50 h.p., and behind this, at the extreme right, appears the front edge of the universal support, which is arranged to ride inside the bore.

Power Required for Honing

For effective cutting, at least 1 h.p. per inch of diameter bore is essential, and many modern hones carrying 100 sq. in. or more of active abrasive surface will usefully absorb much more power than this. A common mistake is to run a large hone with too little power, which has the effect of glazing the stones and producing a condition where further cutting is impossible without removing the hone and dressing the surface of the stones. Less power is required for reciprocating the hone, one-quarter to one-third of the above being adequate.

The traverse movement is best effected hydraulically provided the valve gear is correctly designed to give a sharp cut-off and accurate reversal of the hone at the same point on successive strokes. Failing this, there is great danger of the inertia of the hone coming into play as the cut runs off, and carrying it too far out of the bore. Safety dead-stops suitably cushioned should always be provided to prevent this.

Latest Developments

Hones such as that shown in Fig. 6 may weigh 2 or 3 cwt., and be awkward to manhandle when entering and removing from the bore unless a sling or light hoist is provided near the machine. For this and other reasons one of the latest patent applications covers a so-called "ring-hone" of annular construction, in which the heavy central body is replaced by a light disc coupling or spider, and all the essential expansion and control mechanism is near to periphery of the bone. Thus the weight can be reduced to less than half that of a solid hone.

Other new developments concern automatic sizing and means for simplifying the gauging of bores whilst honing is in progress. At present, automatic sizing by contactors or by electrical or fluid measuring apparatus carried on or near the hone has a limited commercial application, partly owing to the speed and perfection to which manual operation has been brought. When it is considered that with automatic indexing fixtures for loading while honing, the floor to floor production time for average cylinder liners for a 10-h.p. car is as low as 40 seconds to remove up to 0·004 in. stock, it will be apparent that the heavy extra cost and complication of automatic sizing devices is hardly justified to save a further 2 or 3 seconds per bore.

A simple instrument can, however, be used to avoid loss of time during gauging, as shown in Fig. 7. This shows a direct-reading gauge which may be applied around the driving universal of the hone by merely stopping the machine with the hone near the bottom of the stroke, instead of having to raise the hone out of the bore or remove it entirely for applying the older type of gauge. The instrument is of the 3-point contact type, and may be instantly set for any diameter from 3⅜ in. to 6½ in.

E. D. B.

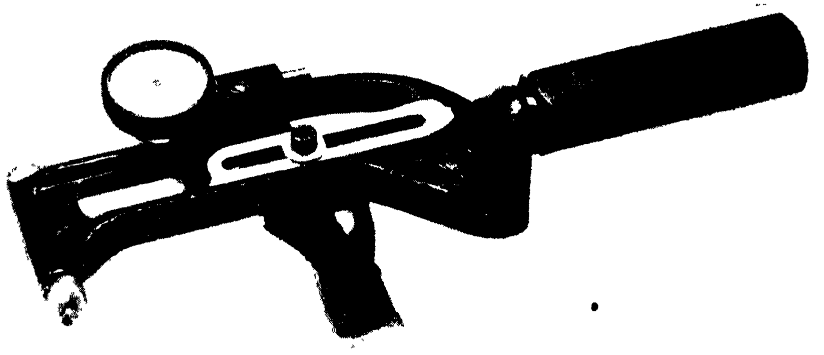

FIG. 7.—ADJUSTABLE GAUGE FOR CHECKING DIAMETER OF BORE WITHOUT REMOVING HONE
(*George H. Alexander Machinery, Ltd.*)

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The usual lap materials are cast iron, brass, copper, and sometimes *mild steel* (i.e. steel of low carbon content, relatively ductile). We shall have more to say on this point later. Meantime, it may be remarked that softer lap materials cut at a faster rate, give rather less precision of finish, but against this wear more slowly and produce a brighter finish, than harder materials. It should also be noted that the density of the material plays a considerable part in its performance. The greater the density, the slower the cutting. The table on page 429 gives a suggested list of lap materials classified according to their particular uses.

On these materials a few notes may be made. Copper, for example, is quicker to pick up the abrasive particles than cast iron, and is freer cutting. It is good for hard steel, especially tool steels. On the other hand, cast iron gives a better finish. Lead has the drawback that it soon becomes deformed, but as against this, it is readily formed, low in first cost, and picks up the abrasive particles quickly.

Abrasive Materials

Abrasives designed for lapping may be either synthetic or natural. Diamond, garnet, and emery dust are natural; aluminium oxide and silicon carbide are synthetic. Of these, the three most commonly employed are: silicon carbide, for

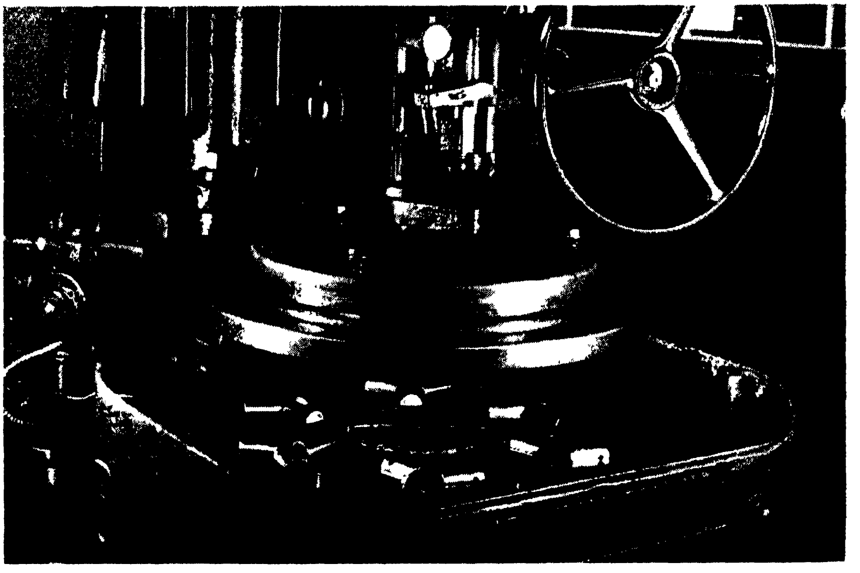

FIG. 8.—LAPPING DAIMLER OIL-ENGINE TAPPETS ON B.S.A. LAPPING MACHINE

The components are located and are free to rotate in slots cut in wooden discs. The lapping wheel is attached to the top plate and is dressed by the diamond at the side. Top and bottom plates run in opposite directions and the total stock removal is approximately 0·0002 in. on the diameter. (*The Daimler Co., Ltd.*)

Material.	*Class of Work.*
Brass	Ring gauges. Thin steel rods.
Copper	Finishing poor surfaces. Removing excessive material. Thin rods.
Felt	Final surfacing of dies and moulds. Precision work on ball-bearing raceways.
Fibre	Worms and worm gears.
Iron, cast	Chasers, cutting tools, gears, gauges, plungers, crank-shafts. Hand lapping. Maximum accuracy.
Lead	Badly surfaced ball-bearing raceways. Large cylinders. Rough-finishing dies and moulds.
Leather	Ball-bearing raceways.
Micarta (a synthetic insulating material mostly composed of mica).	Worms and worm gears.
Steel (low carbon)	Accurate finishing of small holes.

gears and other parts made of hard steel; aluminium oxide for lower carbon steels; garnet for reduction gears. Diamond powder is employed when extremely accurate small work is required and for tool lapping, etc. It is manufactured from a commercial "black" type of diamond produced in Brazil, crushed and classified into varying degrees of fineness.

It is not our purpose, nor is it necessary, to describe the methods by which these various abrasive powders are classified into their different finenesses. The first point to be made is that they need not be coarse. The range available is from 60 to 1,000 grit, but in practice 150 is the coarsest usually employed. The finest powders are employed for extremely accurate soft-lapping operations.

The Vehicle

The abrasive is not rolled into the lap dry, which would produce only a scratched and scarred work surface. The particles must be suspended in a fluid, technically termed the *vehicle*, and this may be either grease, oil, water, or a volatile spirit such as alcohol, according to the purpose. The lapping material can be bought ready-mixed, which gives a more constant blend, or can be mixed by hand on the spot. It is here that the operator's experience is essential, as without it it may be difficult both to maintain uniformity and to ensure the correct abrasive mixture for the actual operation.

In general, the best finish is given by the vehicle of heaviest body, but the amount of material removed per pass is less. Where maximum cut is the essential factor, it is necessary to employ alcohol, but then the operator must put up with a less attractive finish.

The fundamental requirements of the vehicles are ability to keep the abrasive unalterably in suspension irrespective of circumstances; to be little, if at all, influenced by fluctuations of temperature; to give maximum cut possible combined with high quality of finish; to minimise frictional heat; to have no corrosive effect on the work surface; to be non-toxic and non-injurious to the human skin; and to necessitate no potentially dangerous cleansing agent for its removal.

Charging the Lap

The actual charging of the lap is carried out in accordance with the precise form of the tool. When the lap has a cylindrical form designed for finishing external surfaces, the most effective practice is to load the internal surface by means of a roller made of hard steel, which rolls into this surface a previously applied film of the abrasive mixture. The roller has a diameter slightly less than that of the lap itself.

To charge a lap of similar form for work on internal surfaces, the first step is to pass an arbour through the lap. A rectangular piece of hard steel is then given a film of the lapping compound by first applying a suitable quantity to the surface, and then distributing it by gentle rubbing with a solid piece of copper or cast iron, also of rectangular shape. The lap is then rolled upon the steel, using pressure adequate to ensure thorough loading of its surface with the particles.

A lap of rectangular shape should have a perfectly true working surface and should have been *scraped*, i.e. made perfectly flat by scraping it with a special tool. It is charged by first giving its surface the necessary light film of the mixture, which is then forced in by means of a block of hard steel, minimising lateral or longitudinal motion of the block. After a time the lap will appear to be loaded. It should then be cleaned and inspected. Its surface, if correctly charged, will be an even grey, but if shiny patches are found, further work with the steel block and the mixture will be required.

As soon as the even grey tint reveals that the work has been satisfactorily completed, the lap can be used, and no further charging should be attempted so long as it goes on working efficiently. Care must be taken, however, to avoid too heavy a charging of the tool, as this produces a rolling action between the lap and the surface to which it is applied, which will cause the work to lack dimensional accuracy.

A lap of the revolving type is charged by coating a hard steel plate with the abrasive mixture. The lap is placed on this, and a second, uncoated plate is then applied to the lap, which is caused to roll between the two, the rolling pressure serving to embed the lapping mixture in the rotary lap surface. The charged tool is then cleaned by washing it in benzine.

LAPPING MACHINES

There are various types of machines employed for lapping. They may be broadly divided into two groups, (*a*) those that can be employed for lapping both flat and round work, and (*b*) those that act on the centreless principle. In the (*a*) group, the laps may be of cast iron; a non-ferrous alloy, such as bronze; a disc wheel of bonded, fine abrasive type; or a coated paper or cloth abrasive, such as sandpaper.

The type of work that can be lapped depends on the work-holding device. When the machine employs cast iron or bronze laps, only one lap rotates, the other being fixed, and the work holder is rotated at about 50 per cent. of the

revolving lap speed. When machines using discs of bonded abrasive are used, the discs rotate counter to one another, but their speeds differ slightly, and the work holder is made to rotate at a rate of about $2\frac{(S_1 - S_2)}{3}$, where S_1 is the speed of one wheel and S_2 the speed of the second wheel.

A general indication has already been given of the scope of the cast-iron and bronze laps, but while these have still a useful place in industrial lapping, the modern tendency is to use the disc wheel with an abrasive of extremely fine type. This is because cleaning the work to eliminate abrasive compound after lapping is easier, if required at all, which it rarely is, because a lubricant is always used in this process. In addition, though this is not primarily of interest to steel users, there is less likelihood, when non-ferrous parts are lapped, that the work will become impregnated with abrasive particles, and react upon other surfaces with which it is brought into contact. Lastly, they are speedier in operation on comparable jobs. Precision finish is also more readily obtained with the wheel machine. These machines may have either vertical or horizontal spindles, but the horizontal type are mostly confined to machines using hard, fine disc wheels.

The use of sandpaper lapping machines, in which cloth or paper is coated with the abrasive (either silica sand or some special abrasive), is largely confined to parts such as camshafts and crankshafts, in which precision finish combined with a superlatively good surface are required.

Centreless Lapping

Centreless lapping is designed for maximum output of lapped cylindrical parts in a given time. The work must be capable of being fed between the lapping wheel and the controlling wheel, and given this condition virtually uninterrupted lapping is obtained. If the work has a form that departs to some extent from the purely cylindrical, it may be possible, nevertheless, to accommodate it by means of special fixtures, whereby the part is not passed or fed in transversely to the wheels, but is lowered into place.

Vertical Spindle Lapping Machines

For laps of cast iron or soft and porous metal, the method of holding the work and the rate of rotation of the work holder have been indicated. It may be necessary, however, when work to extremely fine limits is required, to employ a fixture carrying a number of parts. The vertical spindle machine is almost exclusively used for these laps, and after a certain amount of lapping has been done—say five minutes—the operation is suspended to allow the parts to be changed about in the fixture. Work is then resumed, and further transpositions effected, until errors in size at different points have been discovered and corrected. The lapping is then concluded.

Cast-iron laps for these machines are provided with furrows and ridges in which the abrasive particles may be held together with swarf. Such channels or recesses also assist in preserving a more uniform service. Either round or flat work can be carried out.

When a bonded abrasive lap is used instead of a metal lap, it is still possible to lap both flat and round work. The pressure used ranges from 1,200 lb. for finishing to 1,800 lb. for roughing.

Horizontal Spindle Centreless Lapping Machines

One advantage of this type of machine is that its action is different from that of the preliminary grinding machine, so that its effect is to remove the original grinding marks and leave only the less objectionable marks along the circumference. The wheels used are of the same diameter, the lapping wheel being no larger than the controlling wheel. A typical measurement is 14 in. diameter by 22 in. wide. The lapping-wheel speed will be in the region of 400 to 950 surface feet per minute, the faster speeds giving a less degree of finish. The controlling wheel, on the other hand, runs at from 200 to 400 surface feet per minute, and in this instance it is the slower speeds that are productive of the poorer finish.

Sandpaper Machines

The special advantage of sandpaper machines is that they provide a form of lap that is liable enough to conform to the shape of the work. On the other hand, they cannot eliminate the ring-shaped or *annular* scratches, nor do they reveal errors arising from vibration, irregularity of surface, lack of parallelism or circularity, etc. Moreover, the surface they give may be deceptive because bright and shining, yet not strictly true when microscopically examined. Such machines have a horizontal spindle.

Lapping Speed

The speed at which a lap revolves has no influence on the result so long as it is below 800 surface feet per minute. If this speed is exceeded, a superior surface finish may be produced, but the work will not be so rapidly done. In centreless lapping, however, the wheel speed may affect the finish, as may the work speed or the grade of wheel.

Accuracy

A good general finish on flat work produced by lapping on ordinary machines will be $\pm$ 0·000025 in., and close limits can also be worked to as regards flatness and parallelism. In centreless lapping the limits range from 0·00005 in. to 0·000025 in. for straightness.

Holding the Work

The method of holding the work in those machines not of centreless type varies according to the job. Flat parts can be laid on a circular disc provided with holes, or carried by intricate devices so arranged as not only to keep them firmly in position, but also to ensure the requisite degree of dimensional precision combined with balance and wear on the laps.

Circular or cylindrical parts are carried by a work-holding device to which is given an eccentric movement, and this causes the work to move in a special relation to the surfaces of the laps.

LAPPING OPERATIONS

Dies and Moulds

We will now consider various lapping operations in greater detail, beginning with the lapping of dies and moulds. This should be done with a formed abrasive rod or *stick*, employing a silicon-carbide loose compound. The two together enable the final forming and rough finishing to be carried out with an excellent finish and no decline in production, while if the work is efficiently done, less time will have to be spent on polishing and other later operations.

On examination, the work may be found to show a few marks, in which case it should be further lapped by means of a suitable silicon-carbide grease and a softwood or cast-iron lap. Finishing must then be undertaken, using an aluminium-oxide grease of the same fineness as for scratch removal, with a wooden or cast-iron lap, or, for tiny parts, an orange stick. Any lapping marks can be eliminated by a finer grease of the same type with a leather lap. For polishing, the type of lap employed depends on the brilliance desired. Normally an aluminium-oxide compound with a hard white felt lap will suffice, but for superfine polishing, a soft rag lap is preferable.

Plug Gauges

As a typical example of the lapping of parts having a cylindrical form, we may take a plug gauge. This should be carried out with a lap of cast iron because of its superior performance and longer service life between chargings. The work is given a lapping allowance ranging from 0·001 in. to 0·0002 in. according to the condition of the surface antecedent to lapping, and whether lapping is by hand or machine. A greater allowance must be left on for hand lapping. The lap will be of the form shown in Fig. 9 (*A*). The work is caused to revolve at the same speed as was employed in the original grinding operation, as governed by the gauge diameter. The lap is maintained in full contact with the work surface, but if the gauge is of massive section, it may be desirable to hold the lap down with a wooden clamp. The lap is now slowly oscillated over the surface from one extremity to the other. The abrasive employed depends on whether speed or finish is the greater need. The finer grit gives the better finish, but does not remove metal so quickly. Care must be taken not to force the lap too heavily into the work, as this pulverises the abrasive particles.

As soon as the gauge is about 0·0002 in. off the final dimension, it must be given time to cool, and finished off by hand lapping in a longitudinal direction. This eliminates "hills" caused by mechanical lapping, gives a truer surface, and improves the finish. The importance of cooling the work before the final operation is that it gives the gauge, which has suffered an enlargement of volume as

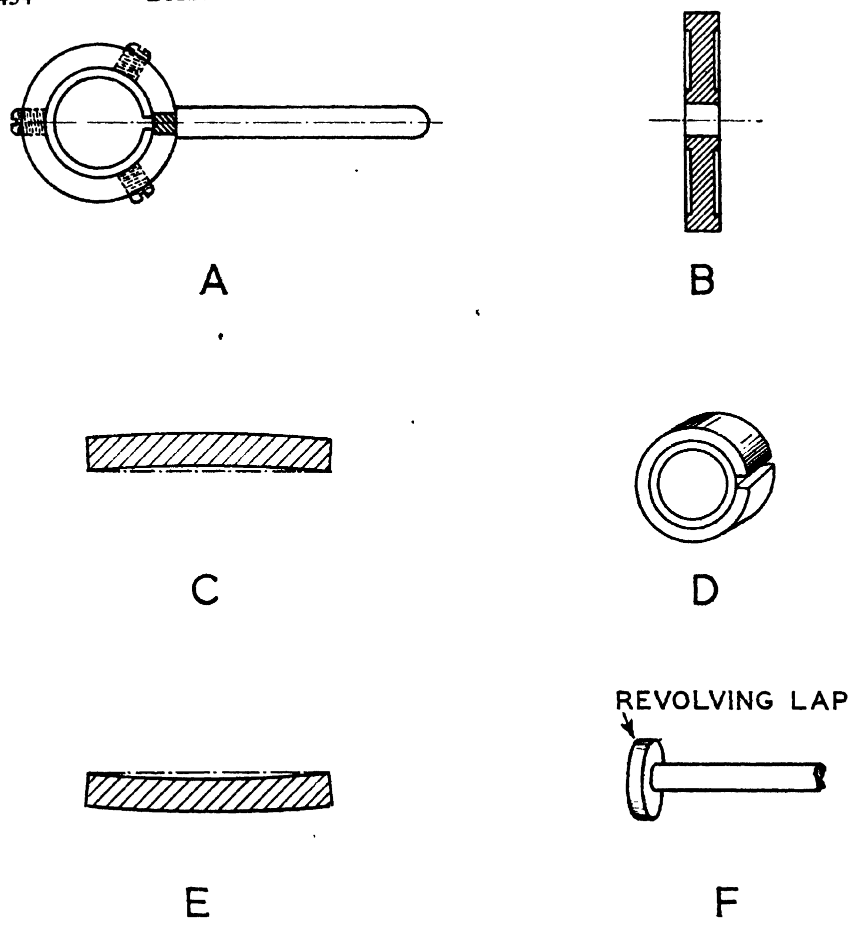

FIG. 9.—LAPPING OPERATIONS

A. Form of lap for plug gauge. *B*. Revolving lap for flat surfaces. *C*. Illustrating concavity. *D*. Split bush lap. *E*. Illustrating convexity. *F*. Revolving lap for extremely small diameter holes.

a result of frictional heat, time to contract to its proper dimensions, so that when finally lapped there will be no major volume change, caused by contraction, to make the finished dimensions inaccurate.

Polishing is then carried out with an aluminium oxide paste of very fine grit, after which the work is dried, and given a final buffing with a clean, dry soft cloth, the degree of final polish depending on the softness of the cloth.

Whether the work should be done by hand or machine depends on the number of similar gauges to be lapped.

Ring Gauges

Ring gauges are liable to become *bell-mouthed*, i.e. the open end expanding or spreading out with an increasing diameter. This may make it necessary to provide an additional lapping allowance on the ring, and this bell-mouthed portion is cut away to leave a perfectly straight-sided hole. The lap employed should be of cast iron or brass, of *expanding* type, i.e. capable of mechanical expansion as required to adjust its diameter. The gauge is caused to rotate, and the lap in turn rotates in the hole of the gauge, being charged with a fine-grained aluminium-oxide abrasive for small holes, and a somewhat coarser abrasive for holes of greater diameter. A final polishing follows.

Flat Surfaces

The cast-iron lap is generally used, and must be given a perfectly true flat surface. Consequently, great care must be employed in its manufacture. Planing must first be carried out on the surface, with minimum effective clamping pressures so as to avoid stresses. Scraping with a suitable scraping tool must next be performed, using as check a standard *surface plate*, i.e. a metal plate brought to the highest degree of surface accuracy and used for testing the truth of work in course of preparation. These plates are made in numerous sizes and are stiffened by ribs below. (Incidentally, some flat laps are provided with ribs in a similar manner.) The lap is tested by rubbing it on the plate, so that any prominences are perceptible by the marks caused. These prominences are scraped until they disappear.

The lap is thoroughly, but not excessively, charged, washed, and a little paraffin applied to its surface to provide a film of moisture which helps the lap to produce accurate work. The part to be lapped is then moved about on the lap surface, each time using a different area of contact. Too much pressure must be avoided, as this spoils the surface of the lap. No further abrasive should be added.

It is also possible to lap a flat surface with a revolving lap, of the form shown in Fig. 9 (*B*). This is made of low-carbon steel. Some laps of this pattern have bevelled edges to give only a small lapping area, and are placed on arbors for use in a surface-grinding machine or lathe. So located they can be employed for work on sharp corners or delicate parts made of hard steel, where it would not be possible to use a disc form of abrasive wheel. Even when a flat lap used by hand is perfectly accurate, it can develop a surface having an undesired degree of curvature, either convex or concave. For all normal flat lapping there should never be any difference between the temperature of the lap and that of the work, as this produces a warping and lack of precision. As a general rule, if the lap is colder than the work, the result will be a slight convexity in the work, and, vice versa, if the lap is warmer than the work, a small amount of concavity will be developed. Let us see why this is.

Avoiding Distortion

In hand lapping, the work is often gripped by the hand, and is therefore more generally warm than the tool. The work surface brought into contact with the lap is therefore slightly chilled, so that the superficial metallic layers shrink, the body remaining fairly warm. The shrinkage causes a concavity as in Fig. 9 (*C*) (exaggerated), and is almost certainly invisible to the eye. It will be obvious that the lap bears only on the ends, as shown, and these are therefore the first layers of metal to be removed. It might be imagined that when this had been done, the result would be a perfectly true flat work surface, but actually, when the work is completed, the chill of the lap is no longer drawing away heat. The

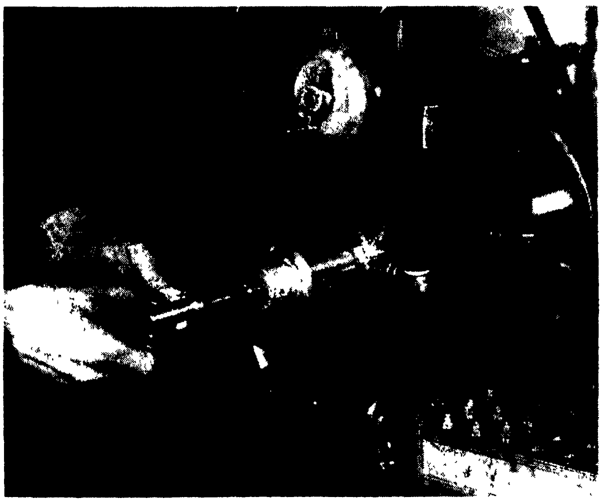

FIG. 10.—LAPPING FUEL-PUMP SLEEVES ON A SUNNEN LAPPING MACHINE
The diameter of the lap can be adjusted by means of the lever fitted with an indicator dial.
(*The Daimler Co., Ltd.*)

work still retains warmth from the hand, and this warmth is now able to diffuse over the entire piece, with the result that the layers previously contracted warm up again, and expand, so that a degree of convexity now occurs as in Fig. 9 (*E*), also exaggerated, and the surface is no longer true. Wherever possible, therefore, it is better to use a work holder so as to maintain both work and lap at an equal temperature. Care must be taken, however, to see that the holder does not exert any heavy pressure on the work, or some distortion may arise.

Thread Gauges

The only significant difference between the lapping of thread gauges and that of the previous types of gauges discussed is that laps for these have the

orrect threads formed in their working surfaces. The work must be made to evolve in the opposite direction, so that each thread contour is of precisely the ame formation, after which the lap goes back to the point from which it began. 'he coarser the thread, the coarser the grit of abrasive, usually of aluminium-xide type. When the number of threads to the inch exceeds ten, a finer abrasive hould be used, or where threads of extreme fineness are required, an aluminium-xide grease.

'hread Chasers

As with thread gauge laps, chaser laps have the threads formed on them, nd are made of cast-iron when of diameter larger than ½ in. or of brass or opper when smaller in section than this.

The lapping operation is carried out in a lathe, and the lap is made to revolve, he work-steady or -rest being carefully regulated to ensure that the work will ot be inclined in any direction when in the flat position. The lap has an luminium-oxide compound brushed on to it with a thin brush. The work is ently held against the revolving lap by manual pressure, and the lap itself will ause the work to perform a traversing movement, the operation being repeated ntil the desired result is obtained.

'ylindrical Work

Cylindrical parts are lapped with the work revolving instead of the lap, vhich is leather-lined and of "lemon squeezer" type. Only one-half of the lap is oated with the abrasive compound, which half is coated is immaterial. The lap s oscillated to prevent the straight lines that would otherwise be left, and a ood deal of pressure should be employed. The fineness of the abrasive depends n the degree of finish, being less for roughing and greater for a fine lapped inish.

Bearings

These are lapped with an aluminium-oxide grease, and it is claimed that this nethod of finishing machine-bearing surfaces minimises the amount of *running* n necessary, lengthens the service life of the bearing, and gives the moving parts f the machine in which they are used greater rigidity. It also does away with he need of regrinding, or, where this cannot be avoided, eliminates burr, and o improves the performance of the bearing. Moreover, the work can be carried ut on site, without removal of the part to a different shop. It must be pointed ut, however, that where a bearing is not in proper alignment, the error must be orrected by use of the scraping tool.

The work or the lap should be oscillated to eliminate lapping lines, and eriodically lubricated with a little machine oil. If the bearings are of tapered orm, the spindle must be elevated every now and again so that the abrasive nixture may flow in the direction of the tapering ends. The work must be horoughly cleaned when finished with a solvent, and then given a good rinse in hot soapy solution.

Holes

Various methods of lapping holes can be adopted, according to the dimensions of the hole and the degree of precision required. The lap is usually of cast iron or copper and of cylindrical form, constituting what is commonly termed a *split bush* (see Fig. 9 (*D*). A *bush* is a cylindrical sleeve or tubular piece). It is placed on the smaller end of a tapered arbor (approximately 2° of taper) and the split down one side gives it expansibility, so that by pushing it farther down the arbor towards the thicker end it can be made to allow for the increase in diameter of the hole as it is lapped. It is usually considerably longer than the hole, and its thickness is from one-sixth to one-eighth the diameter of the work. It is moved in and out of the hole so as to lap the whole surface.

Abrasive compound must be sparingly used towards the end of the operation, so as to prevent wide-mouthed holes, caused by excess of abrasive grains under the edges. Otherwise the practice is as for lapping cylindrical work, particularly plug gauges.

It should be noted, however, that a revolving low-carbon steel lap of the type indicated in Fig. 9 (*F*) can be employed in bringing holes of extremely small diameter to precision limits. The work is done in a lathe with hand traverse of the revolving spindle. The abrasive used is made up of powdered diamond in a suitable vehicle, usually oil. Little pressure should be employed, and paraffin should be the lubricant. The speed of the lap is governed by its diameter, but is as high as possible. If the work is extremely soft, an alternative abrasive compound must be used, to prevent loading of the work surface with diamond powder.

Conical Holes

This is best carried out with a revolving lap. The first step is to see that the hole to be lapped is reasonably to size, plus a small allowance for the lapping operation. The lap should be of copper, and of the same form as the abrasive wheel, but of greater width. The same speed as for the final grinding should be employed, but not exceeded.

Gauge Blocks

This is a most important operation. Gauge blocks are blocks of metal, flat, parallel, and to a specified size within 0·000001 in., used as a quick method of checking dimensions. For lapping they are brought to about 0·001 in. of the final dimension. About twenty of these blocks are then placed in a work-holder, usually provided with holes to receive them. This enables them to be revolved and amply oscillated. There are two cast-iron laps, exceptionally accurate, one fixed to the machine base, and one held by an arm so that it may travel easily in the desired directions. Neither lap revolves nor oscillates, but the top lap *floats*, i.e. it can be swung out of the way temporarily to reveal the bottom lap and the blocks. It is only the force of gravity that enables it to rest on the top side of the work. Thus, the work is between the laps, so that the blocks can be lapped top and bottom at one and the same time.

The blocks travel over the lap surfaces in an intricate path so as to ensure that the laps wear uniformly. Every block makes contact with the whole of the surfaces of both laps. The first lapping is not of long duration, as otherwise excessive heat would be generated. The machine is stopped, therefore, and the top lap elevated and swung aside to allow the work to be reached. The blocks are then individually transposed, i.e. replaced systematically by the diametrically opposing block, every block being moved 180° or 90° on occasions when maximum accuracy is required. This alternation of lapping and transposition goes on till each block is identical in height with the rest, after which they are measured and finish lapped.

The reason for transposition of the blocks is that otherwise it would be impracticable to obtain two opposite surfaces that were both flat and parallel. This is because the top lap rests on the three peaks or highest spots of the unlapped blocks, and if not then parallel to the bottom block, will stay so, causing lack of parallelism in the blocks. A transposition of 180° cuts down the error by one-half.

The abrasive employed is Turkish emery. A little extra emery is added after the work has been in progress a short time, being mixed with paraffin. The speed of revolution of the work has no effect on the rate of removal of the metal.

Steel Specimens

In preparing sections of steel for examination under the microscope, lapping is sometimes employed as a finishing operation, to give the final finish. Loose abrasives are used, either floated in water, which is mechanically stirred to maintain uniform suspension of the grains, or preferably, in a compound that will hold the grains more firmly, so that they are not detached and flung off centrifugally by the revolving lap. These are then charged into a material tightly stretched over a revolving disc of metal, and the material charged with them may be either cloth, white felt, or chamois leather. A rough lapping is followed by a finishing lap, after which polishing with a chamois leather charged with abrasive concludes the operations.

Surfaces of metallographic specimens so produced are, however, not really suitable for research and laboratory purposes, and lapping with loose abrasives is being steadily replaced by the use of a bonded abrasive, while there is every reason to believe that eventually the super-finishing process (see page 441) will be adapted to this type of work and extensively used.

Gears

The subject of gear lapping is far too intricate to be dealt with comprehensively here. The writer will therefore confine himself to a few general indications of modern practice. Lapping is used on gears as a means of eliminating tool and grinding marks, rectifying slight flaws in contour and pitch, and any small degree of warping resulting from carburising, hardening, or other processes, and of giving a finish that will render the gears quieter and less liable to generate frictional heat in service. Lapping can also be employed to restore

to use gears that have been rejected by reason of minor superficial faults.

The gear is lapped in a lathe or special machine, and its teeth given a coating of the abrasive mixture over the whole of their surfaces, as soon as the gear begins to revolve. The compound should be put on with a brush. Cleaning after completion of the work is essential. For general lapping work on gears that have been hardened, a silicon-carbide grease should be used, progressively finer as the desired finish is smoother. For the final smooth finishing, a grease containing garnet should be used, the finest surface on small gears being produced with a garnet of floury consistency.

Where the gears are in the unhardened condition and made of low-carbon steel, the lapping compound should be free cutting, and produce a good, smooth surface, while not itself loading the work. Aluminium-oxide grease should be used, of fineness suited to the finish required, when rate of production is the most important factor. For a lighter cut or a better finish, garnet grease should be adopted. It is also possible to employ a more fluid mixture than either of these, with soluble oil as the vehicle, for more protracted lapping. If the work loses moisture after a time, water should be applied.

Crankshafts

This type of work may be carried out either manually or mechanically. The lap may be lined with leather or consist of paper coated with an abrasive material. The lap is oscillated; and the work caused to rotate. The abrasive is preferably aluminium-oxide grease, of fineness increasing as the work surface is required smoother. A good deal of pressure should be exerted and the lap oscillated.

Lapping by Lead Wheel

One form of lapping that calls for brief mention is that performed by a lead wheel. The machine employed is a standard grinding machine, and the operation is designed for the lapping of parts having a cylindrical form. The diameter of the wheel should be no larger than is essential, and its width about 50 per cent. that of a normal grinding wheel. The same care must be taken to ensure true running and balance, as with abrasive grinding wheels. The work is given a light coating of aluminium-oxide abrasive suspended in an oil vehicle, and the lead wheel is fed in so that such pressure as it exerts is applied to the abrasive and not the work, with which it must *not* make contact. For fine finishing, a much finer grit can be used, and a second lapping with this carried out. The wheel speed should not exceed 2,000 surface feet per minute. The work is rotated at a speed giving minimum chatter, and the wheel is slowly passed across it.

It must be borne in mind that lapping is not the same as *honing* or *super-finishing*, which form the subject of the preceding and succeeding articles, though it is frequently confused with them. It is hoped, however, that after a reading of these three articles the reader will be clear as to their respective uses and advantages.

E. S.

3.—SUPERFINISHING

There are a number of operations in the factory and tool-room that call for a high degree of finish, but before these are discussed, it is as well to remember that the finish required should be as good as, but no better than, is actually called for by the work. Considerable sums can be wasted by giving a better finish than is necessary. With this caution, a few typical operations in the tool-room can be dealt with.

Polishing Reamers

The grinding of reamers is one of the most important jobs in the tool-room, because any slight error in the clearance angle exercises a considerable influence on the performance of the tool. Shell reamers necessitate for their grinding special equipment if they are to be dealt with in quantity. The normal procedure is to give the flutes a preliminary rough polishing, using a wheel of the form shown in Fig. 11 (*A*). The resemblance to the set-up for actually cutting the flutes with a form cutter will be observed. The type of wheel used is one of hard felt employing a proprietary brand of aluminous abrasive in No. 120 grit. The operation is carried out by hand, and the diameter of the polishing wheel corresponds to that of the original form cutter used. A shell reamer $1\frac{1}{2}$ in. in diameter calls for a polishing wheel 2 in. in diameter, revolving at a peripheral speed of 7,000 ft. a minute at least, i.e. a spindle speed of about 14,000 r.p.m.

To ensure the maintenance of so high a speed, it is necessary to embody in a bench polishing lathe a ball-bearing internal grinding spindle. The wheel is used dry, and when the surfaces of the flutes have been rough polished, they are next sandblasted, the object of this being to eliminate all traces of oxide remaining after previous operations, and to show up minute surface flaws.

The flutes are then given a final polish, using a pair of polishing wheels mounted on a single spindle, as shown in Fig. 11 (*B*). The abrasive medium for the first of these wheels is exactly the same as for the rough-polishing operation, the aim being to eliminate the tiny scratches and depressions occasioned by the sand-blasting process. The following wheel employs No. 180 Turkish emery and a grease such as cold mutton fat or stearine. This work is similarly a manual operation.

Grinding Reamers

We now proceed to the grinding operation proper, beginning with the external diameter. For this a special arbor is used, and the work carried out on a standard plain grinder, using an alumina wheel 36 to 46 grit running at about 6,000 ft. per minute. While the wheel should run at the maximum effective speed, care must be taken not to raise the speed so high that the wheel is excessively consumed. By this operation the reamer diameter is brought within five-thousandths of an inch of the final dimension. It should be noted that the clearance shown in Fig. 11 (*C*) must also be ground, but no fine limits have to be observed here.

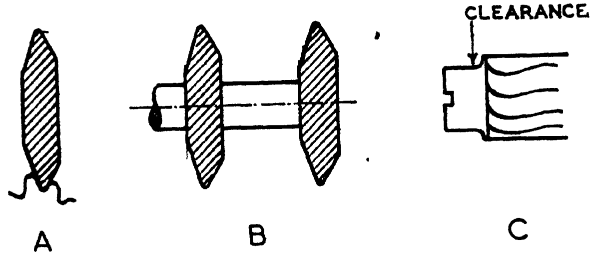

FIG. 11.—FINISHING REAMERS

A. Type of wheel for rough polishing the flute. *B*. Polishing wheels mounted on a single spindle for final polishing the flutes. *C*. Reamer clearance which must be ground, but without fine limits.

The ends of the shell reamer must next be ground. They can be lapped, surface ground by means of a cylinder wheel, or ground with a normal disc wheel, the work being done in a surface grinder when the cylinder wheel is used. On the whole, this is probably the most satisfactory method for the reason that it is possible to grind a plurality of reamers on the one single fixture. The wheel employed is of alumina type, soft grade, 46 to 60 grit. Wheels of bonded silicate type are advisable, but not compulsory.

If the number of reamers to be ground warrants it, it is a good plan to employ two work-holding fixtures, so that as soon as one batch is completed, a previously loaded arbor can be inserted in its place, thus involving the minimum interruption of the flow of work. Where only a single-surface grinder is used, one set of ends is ground, and the other ends ground in a second stage. Otherwise, both lots of ends can be ground at one and the same time by using two machines.

The internal hole must now be roughly ground, which is done on an internal grinding machine, using an alumina wheel of medium soft grade, 46 grit, running at a minimum speed of 5,000 surface feet per minute. The work must be rigidly held on the spindle, as otherwise it will prove difficult to avoid error in the taper of the bore. The checking of dimensions should be done with a taper gauge or gauges.

This completes the rough grinding, and the external diameter must now be finish ground, again using a special arbor of the same type as for rough grinding. In this operation the wheel and not the work is traversed, the wheel itself being of alumina type, medium grade, about 80 grit. The internal diameter comes next, and is finish ground with an alumina wheel of soft grade and 60 grit. There is no need to dwell on the two concluding operations, the relieving of the teeth, which are carried out in the ordinary way as for any other type of form tool.

A reamer of the hand type is usually ground in a cylindrical grinding machine to the requisite dimension, after which relieving of the teeth or blades is carried out by means of a cup wheel of small diameter. After the operation is completed, it is a good plan to eliminate flash caused by the operation by lightly touching up the cutting edges with an oilstone. A taper or lead is given to the entering part of the tool to ensure easy penetration and absence of vibration. The extent of this is approximately $\frac{1}{16}$ in. per foot, but is usually governed

by the quantity of metal to be reamed out. The lead is obtained by means of the swivel table of the grinder. For hand reamers over 2 in. in diameter, approximately $\frac{3}{4}$ in. length of lead is given.

Plug Gauges

Plug gauges are only to be tackled by shops with the necessary range of equipment, because to bring a plug gauge to the desired degree of accuracy may necessitate not only grinding to a high degree of finish, but also such additional operations as lapping, honing or superfinishing.

In general, however, a plug gauge can be brought to within two-thousandths of an inch of the final dimension, and assuming this grinding has been done in such a way as to leave a smooth and well-finished surface, the gauge can be finished off by a lapping operation, using a split, adjustable ring lap of grey cast iron, with an aluminium-oxide grease of 220 grit for the first metal-removing operation, and 400 grit for the final fine finishing stage. Sometimes an additional operation may be required to provide a particularly bright surface, in this case the work is rubbed with a polishing cloth and a paste of aluminium oxide, which is left to dry on the surface. In these lapping operations it is essential not to use heavy pressures.

Most lapping operations on plug gauges are carried out by hand, except where there are a large number of the same size to be completed, in which case machine lapping may be adopted. Any degree of polish over and above what

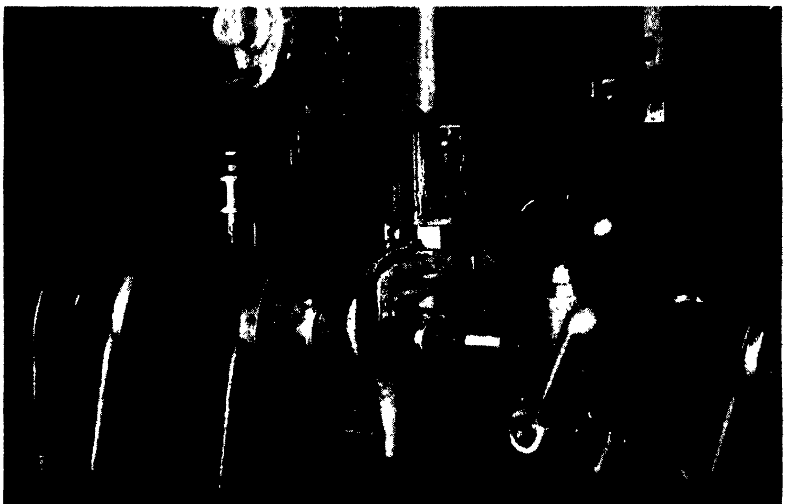

FIG. 12.—LAPPING EXTERNAL BEARING DIAMETER ON AN AUTOMOBILE LAYSHAFT ON A FOSTER SUPERFINISHING MACHINE (*The Daimler Co., Ltd.*)

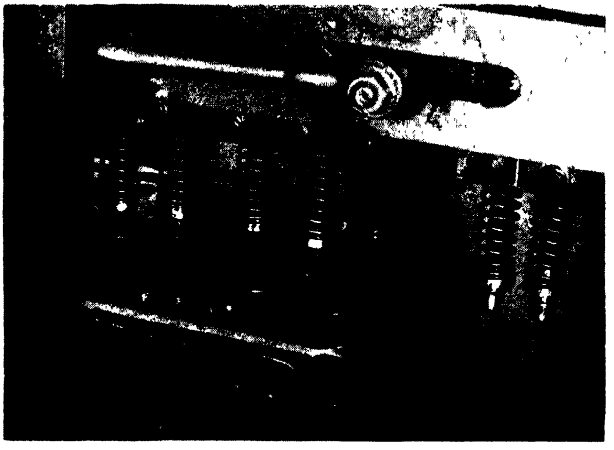

FIG. 13.—FINISH LAPPING WITH A SPECIAL MULTI-HEAD ATTACHMENT

The illustration shows this operation being carried out on the cylinder head of a Daimler engine. (*The Daimler Co., Ltd.*)

has already been described can be given by placing the gauge in a work holder held in the hand. The work holder has centres that allow it to revolve readily when inclined to the radial line of a dry cast-iron disc which itself revolves.

Precision Tools and Dies

In making precision tools and dies, grinding to shape gives highly accurate contours with an excellent surface on hardened steel. If it is desired to grind a form satisfactorily at the least possible cost, there is no necessity to finish, nor is there any special advantage in finishing the shaped work with an abrasive wheel that covers the entire piece. A better result will be obtained if appropriate ribs and projections are ground with thin wheels, making one diameter or height correspond to one ground previously. In this way extremely wide contours may be ground with great precision because the required contours of the wheel are easily provided.

For operations of this type it is possible to employ with advantage a radial truing fixture for truing a wheel to both male and female radii. If the tip or point of the diamond lies to the rear of the centre of the fulcrum, a male radius is obtained; if in front of the fulcrum, a female radius. Using a fixture of this type, it is possible to obtain radii accurate to one ten-thousandth of an inch on a wheel.

It is most important that for such work the grinding wheels should be properly placed on correctly designed spindles and between well-proportioned and well-designed flanges.

When it is desired to give a fine polish to relatively small areas of a mould or die, the best plan is to employ a flexible shaft grinder, with aluminium-oxide cloth cartridges of fine grit, or flexible aluminium-oxide rubber-bonded wheels or points. On the other hand, when large areas are to be given a fine polish, aluminium-oxide rubber-bonded wheels or aluminium-oxide cloth belts on rubber mounts can be employed.

Ring Gauges

Ring gauges are usually left with an allowance of 0·0004 in. for the lapping operation, designed to eliminate the scratches remaining after an 80-grit wheel has been at work upon them. The lapping operation is carried out with a lap of cast iron whose body has a degree of taper, the lap itself being of cast iron, split expanding type, split three ways from each end. This is loaded with powdered emery, which is forced into the lap surface by rolling on a steel plate. The lap is placed in a lathe, and the work passed with a reciprocating motion over it manually. Olive-oil is employed as a lubricant, or if this is not available, a thin machine oil. Emery must on no account be applied directly to the lap, which would injure both it and the gauge.

Precision Boring of Drilling Jigs

A most essential operation carried out in the tool-room is the precision boring of drilling jigs. The final stages of this work involve the lapping of the bores and the external diameters of slip bushes. In carrying out these operations maximum care must be exercised, as otherwise a precision-grinding operation may be spoiled. The type of lap employed for the bores is made of cast iron or a hard type of copper. This tool is machined and ground to the desired dimensions, and given a taper end screw to allow of expansion. It is charged with emery and a lubricating oil, and then given a careful washing so as to eliminate excess emery and lubricant.

The external diameters are lapped by means of a cast-iron block having holes of different diameters, with holes also by way of which the emery and the lubricant are fed. A lap of this type can be charged while in use, but the charge must not be excessive.

Lapping Cutting-tool Edges

Many tools of precision type are being tipped with tungsten carbide, and these need to be lapped so that they may give their maximum cutting power and output per grind. Usually lapping is preferred to honing, because it is a speedier operation and produces a keener cutting edge.

As soon as the tool has been lapped on each side so as to produce a good cutting edge, any further polishing of the surface can be achieved by means of a dry disc set at an angle of 5° to the cutting edge from rear to front. Assuming that it is possible to hold the tool without tilting, the final lapping can be carried out employing a swivelling movement across the direction of rotation from 90° to 0° to the cutting edge, and from rear to front.

Still finer finish is obtainable by means of an extremely fine grit silicon-carbide oil compound, but a point to be noted is that the keenness of the cutting edge cannot be estimated in terms of brilliance of polish. The maximum lapping speed should be 1,200 surface feet per minute.

E. S.

TOOL-ROOM GRINDING

THIS article is intended for the tool-room operator who is responsible for maintaining in a state of maximum efficiency the cutting tools used in the machine shop.

Before dealing in detail with the actual grinding method to be adopted, it is proposed first to consider very briefly the characteristics of the various types of grinding tools which are available for this purpose. A grinding wheel is composed of a bonding material and extremely hard abrasive particles. The grit or grain of a grinding wheel refers to the size of the particles of abrasives used. The sizes are indicated by standard numbers corresponding to the number of meshes in the screen through which they will pass. For example, a 36 grit will pass through a screen having 36 meshes to the linear inch.

The grades of grinding wheels vary from very soft to very hard. Grade, or hardness, of a grinding wheel is a measure of the strength with which the abrasive grains are held in position by the bond, and is not be confused with the hardness of the abrasive grains themselves. In use, a grinding wheel must wear away in order to maintain good cutting properties; therefore, the ideal wheel for any particular operation is one in which the bond strength or grade has been so selected that, while excessive wear is avoided, blunting of the cutting face does not occur.

For all types and bonds, the grade or hardness of the wheel is indicated by letters of the alphabet, ranging from A to Z, soft to hard. The main range of grinding wheels commonly in use fall within the range of the letters F–T. It will be appreciated that the nature of the bonding material which holds the abrasive grains together determines the mechanical strength and grade of the grinding wheel.

Several different types of bond are employed, dependent on the particular requirements, the one most commonly used being what is known as "Vitrified"; thus we have the following types of bond:

VITRIFIED BONDS (SYMBOL V).—Have a wide application over the range of grits and grades, producing wheels and other abrasive articles of high efficiency. The bonds are vitreous in character, and may be regarded as glasses or semi-glasses resulting from fusion of ceramic materials during "firing," a process carried out in kilns at high temperatures. Vitrified wheels are, therefore, somewhat brittle, and must be handled at all times with due and reasonable care.

RESINOID BONDS (SYMBOL B).—Resinoid is a phenolic resin, a synthetic organic compound. Resinoid-bonded wheels are cool cutting and remove stock

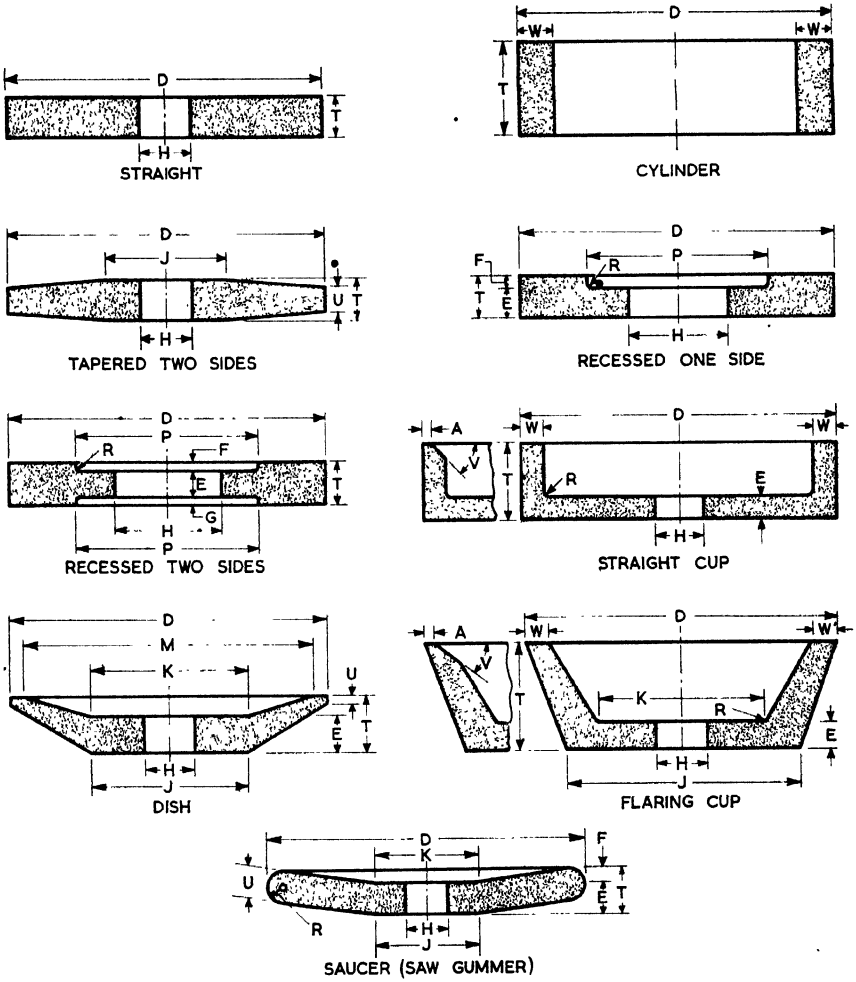

FIG. 1.—STANDARD GRINDING-WHEEL SHAPES

Key to Letter Dimensions

A—Flat spot or bevelled wall
D—Diameter (overall)
E—Centre of back thickness
F—Depth of recess
G—Depth of recess
H—Arbor hole diameter
J—Diameter of flat or small diameter
K—Diameter of flat inside
M—Large diameter of bevel
P—Diameter of recess
R—Radius
T—Thickness (overall)
U—Width of face
V—Angle of bevel
W—Thickness of wall

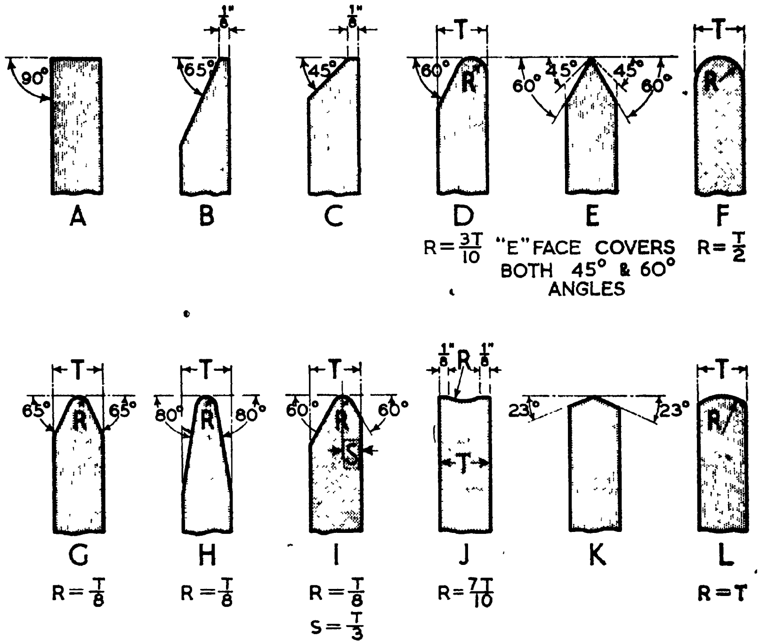

FIG. 2.—GRINDING-WHEEL FACES

rapidly. They are made in many sizes and for many purposes. As cut-off wheels they can be operated safely at speeds as high as 16,000 s.f.p.m. for cutting off all kinds of material. Larger wheels, operated at speeds around 9,000 s.f.p.m., are used for snagging castings, and at normal speeds for finishing cams, roll grinding, and saw gumming.

RUBBER BONDS (SYMBOL R).—Rubber-bonded grinding wheels are used chiefly where a good finish is required. The rubber softens under the heat of grinding, and acts as a cushion for the grains of abrasive so that they do not cut as deeply as when more rigid bonds are used. The rubber also acts as a buff to polish out the grain marks. Extremely thin wheels can be made in this bond because of its strength and toughness. For example, wheels as thin as 0·005 in. are used for slotting pen points.

SHELLAC BOND (SYMBOL E).—Grinding wheels bonded with shellac are classed as elastic wheels. It gives a cool-cutting and good finishing wheel. Since shellac is somewhat elastic and softens under the heat of grinding, it is similar to rubber as a bond, but wheels so bonded cut more freely than rubber wheels and will take deeper cuts without burning.

Material to be Ground

High-tensile strength materials such as carbon steel, alloy steel, and high-speed steel, require the use of an aluminous abrasive such as "Aloxite." Low-

tensile strength materials such as cast iron, brass, bronze, aluminium, and copper, require a silicon-carbide abrasive such as "Carborundum." The harder the material, the softer the grade and the finer the grit required. The more ductile the material, the coarser the grit. The above remarks are subject to an exception in the case of soft iron and stainless steel; these metals have somewhat unusual properties, and either a Carborundum-brand wheel or an Aloxite-brand wheel may be used, depending upon the operation.

The greater the amount of metal to be removed by the grinding process, the coarser should be the grit and the harder the grade of grinding wheel selected. As a general rule it may be taken that the finer the finish required, the finer should be the grit size. In this connection, it should be remembered that quite a good finish can be obtained with relatively coarse grits by proper use of the diamond dressing tool, together with careful adjustment of work speeds and wheel speeds.

The higher the work speeds, the harder the grade required, and the higher the wheel speed the softer the grade.

Size of Grinding Wheel

In general, it may be taken that where a large diameter of grinding wheel is used, the grade should be softer than would be required for the same work using a small-diameter grinding wheel. Consideration should also be given to the area of contact between the wheel and the work, i.e. the greater the area of contact, the softer the wheel. The standard shapes of grinding wheel are illustrated in Fig. 1. It will be noticed that no dimensions are given on these illustrations, which are merely intended as a guide. When it is desired to order a wheel of a particular type and size the user should therefore supply the dimensions, also specifying grit, grade, and bond, in order to enable the makers to provide a wheel with the required characteristics.

TOOL-GRINDING TECHNIQUE

The following is a brief summary of the technique to be employed when grinding the various types of tools.

Offhand Grinding

Lathe and planer tools may be ground on bench stands, floor stands, wet tool grinders or special machines designed for tool grinding, such as the Lumsden or similar machines which grind tools semi-automatically to correct angles, and enables these angles to be duplicated rapidly and easily.

In offhand grinding the tool should be kept moving across the face of the grinding wheel to avoid grinding in one spot. The wheel should be kept running true and cutting freely by frequent dressings with a Huntington or star dresser.

A coarse-grit wheel on one end of the spindle and a fine-grit wheel on the other will accommodate both roughing and finishing operations.

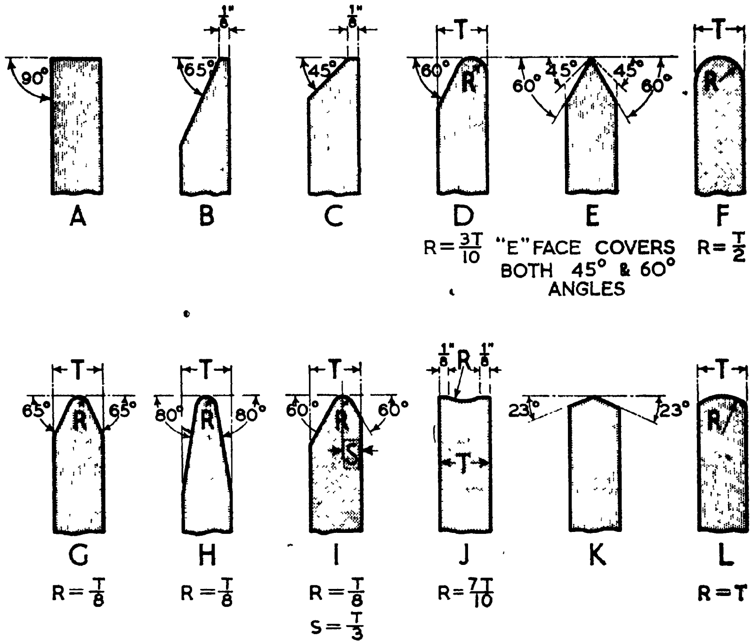

FIG. 2.—GRINDING-WHEEL FACES

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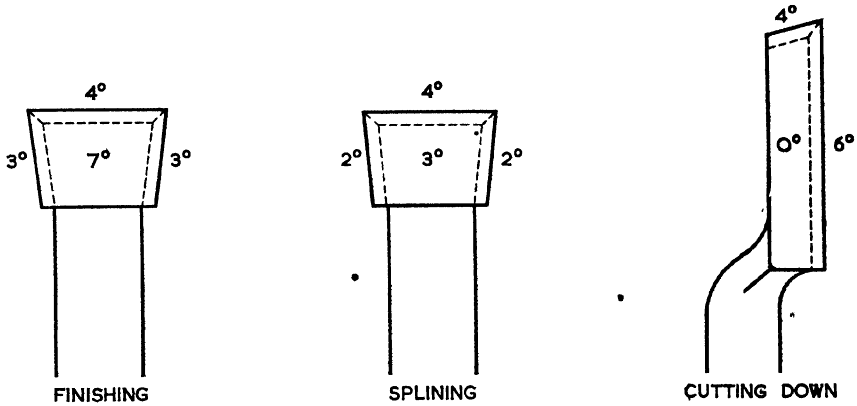


FIG. 4.—CORRECT CLEARANCES AND CUTTING ANGLES FOR SOLID OR ONE-PIECE PLANER TOOLS

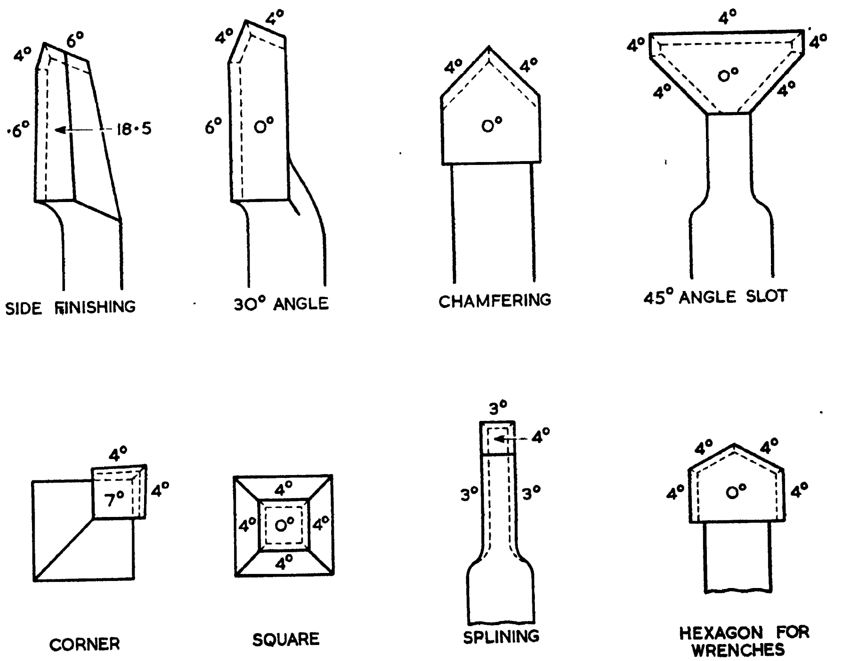


FIG. 5.—CORRECT CLEARANCES AND CUTTING ANGLES FOR SOLID OR ONE-PIECE SLOTTER TOOLS

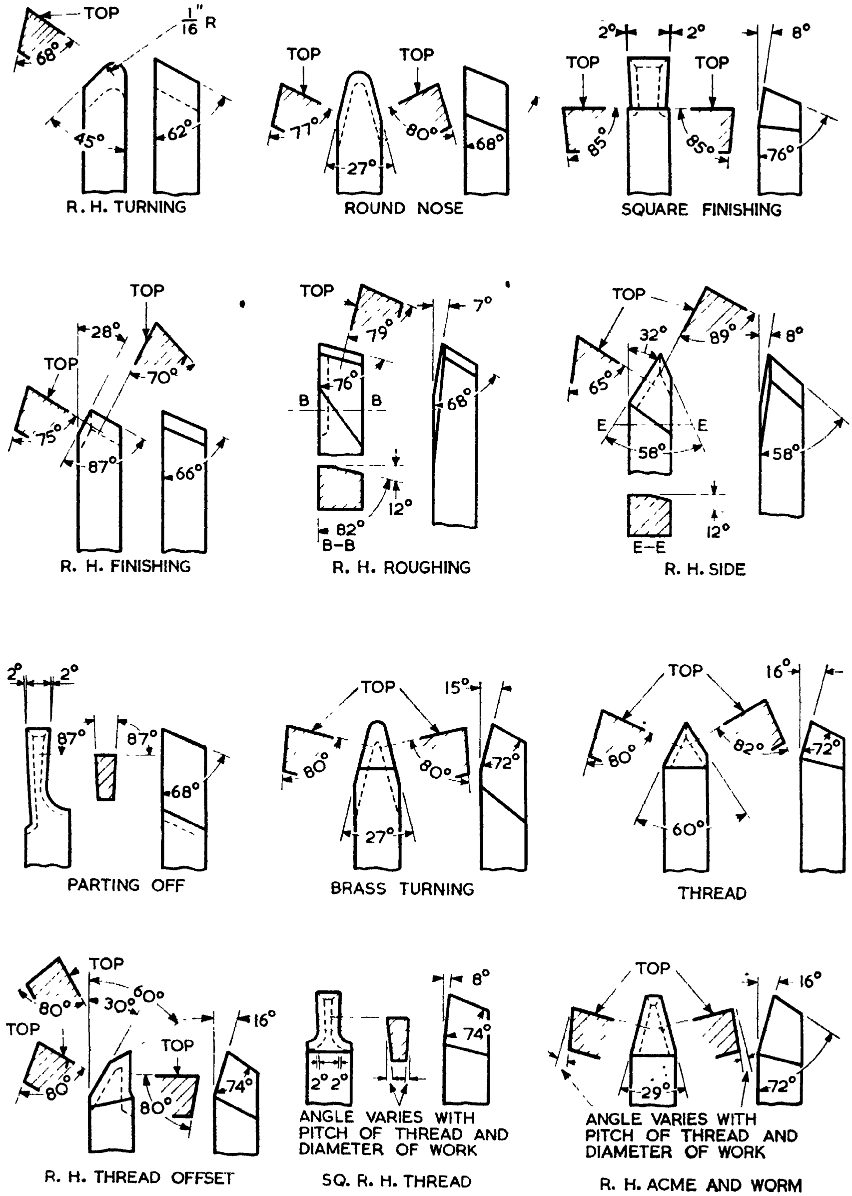


FIG. 6.—CORRECT CLEARANCES AND CUTTING ANGLES FOR INSERTED LATHE TOOLS

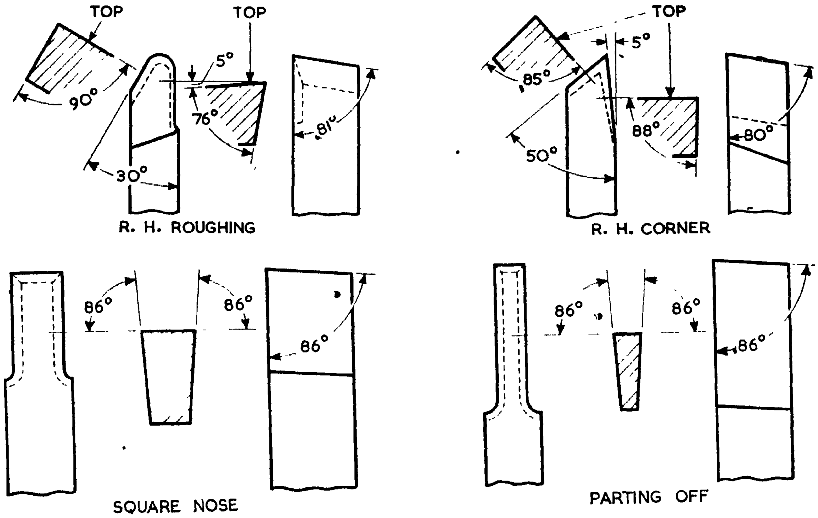


FIG. 7.—CORRECT CLEARANCES AND CUTTING ANGLES FOR INSERTED PLANER TOOLS

The tool must be heavy enough to take the cut without chatter, and have angles proportioned to turn the chip properly and yet preserve the cutting edge. Machine grinding has the following advantages over hand grinding: saves the time of the operator; gives correct grinding angles; increases the life of the tool; increases production; raises the quality of production; permits a smaller stock of tools.

In both the Lumsden and Gisholt tool grinders, the tool to be ground is held in a chuck with various adjustments, so that any angle desired may be ground, and that angle can be duplicated again and again by using the same settings on the angular adjustments of the chuck. The grinding is done wet under a copious supply of water.

The illustrations on pages 450–454 show the correct clearances and cutting angles for the various types of tools used in lathes, planes, slotters, and boring machines. Figs. 3–5 show the correct proportion for solid or one-piece tools, whilst Figs. 6–8 show the proportions which are desirable when grinding in certain cutters that are intended to be mounted in a permanent tool holder of these cutters.

Standard Tools

These may be ground in the holder, but it is better to transfer them to a special grinding holder for the sharpening.

Carbide-tipped Tools

An article on carbide-tipped tools, with details of tool-grinding procedure, will be found on p. 465.

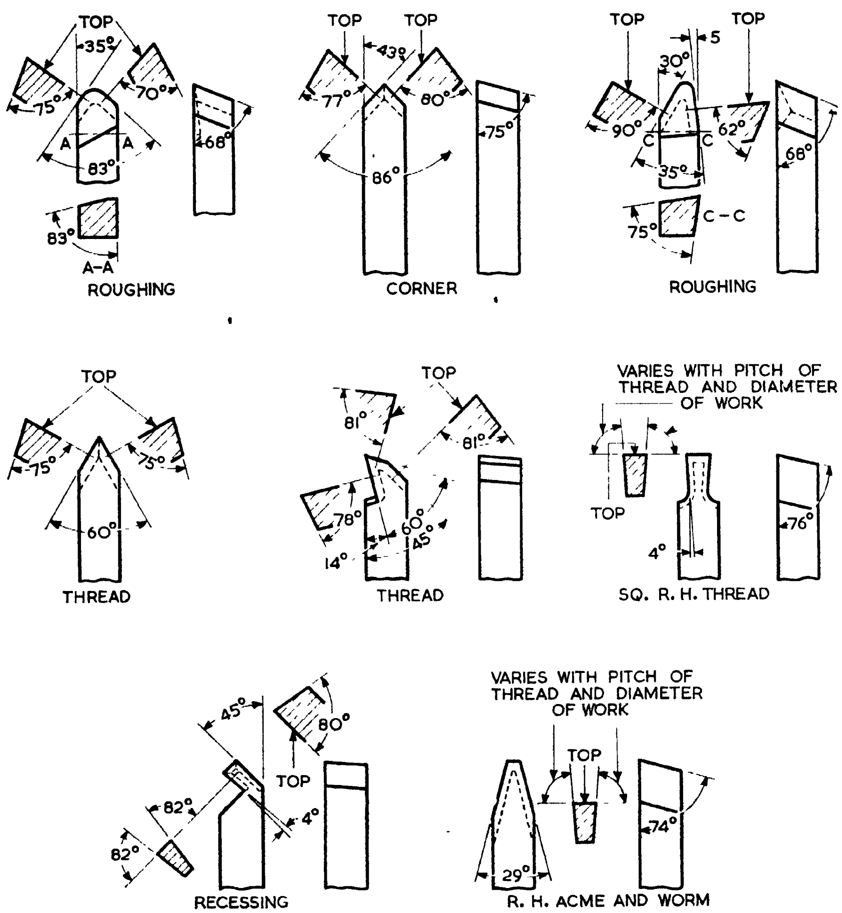


FIG. 8.—CORRECT CLEARANCES AND CUTTING ANGLES FOR INSERTED BORING TOOLS

Milling Cutters

Milling cutters are, in general, made on two distinctly different principles, and each class must be sharpened by methods peculiar to itself.

The first class comprises cutters which are sharpened on the periphery by grinding at an angle behind the cutting edge: the clearance angle is produced by the grinding operation. This class includes milling cutters with straight and spiral teeth, side milling cutters, face mills, end mills, and reamers.

In the second class are cutters which are sharpened by grinding the front faces of their teeth. These cutters have a definite profile for producing a given form to the work which must be maintained, and are generally known as

formed or relieved cutters. The clearance is produced by the relieving operation when the cutters are made. This group includes gear cutters, formed cutters, taps and some types of reamers, and formed tools for lathes and screw machines.

Methods of Grinding Milling Cutters

There are two methods of grinding cutters and reamers based upon the direction of rotation of the grinding wheel in relation to the cutting edges of the teeth. These are illustrated in Fig. 9.

In method A the grinding wheel rotates from the body of the tooth off the cutting edge. The rotation of the wheel holds the cutter on the tooth rest, but the wheel raises a burr on the cutting edge, which must be removed by stoning, and has a tendency to draw the temper of the steel. Method B rotates the wheel from the cutting edge towards the body of the tooth. It results in less danger of burning the tooth, but great care must be used to hold the cutter on the tooth, since the rotation of the wheel tends to turn the cutter away from the rest. If the cutter turns while grinding, a ruined tooth results.

Cup wheels are also used for the grinding of cutters and reamers. The two methods of using cup wheels are similar to those used with plain wheels, and are shown in the diagrams. The same comments regarding the grinding wheels apply to the use of cup wheels. More care, however, should be taken in using cup wheels, because of the greater area of contact between the wheel and the work, and the cuts should be light.

In general, the plain wheels may be used on narrow lands, but the cup wheel should be used on wide lands. However, a plain wheel may be tilted by swivelling the wheel head so that the cut will approach a straight line. Plain wheels are sometimes used on cutters up to 4 in. in diameter, while cup wheels are used on the larger sizes. The diagrams show in an exaggerated manner the clearance produced by both plain and cup wheels. It will be noted that in using a plain wheel, the actual angle at the cutting edge is much greater than the apparent angle. The apparent angle must be large enough so that the heel of the tooth will not drag on the work when the cutter is in use.

CLEARANCE.—Correct clearance at the back of the cutting edge is essential. Insufficient clearance will cause the teeth to drag over the work, resulting in friction and slow cutting, while too much clearance will cause the teeth to wear rapidly and produce chatter. Too much clearance is less objectionable than too little, however. The edge must be kept sharp and the clearance angle correct. A secondary clearance of 9–30°, depending upon the design, produces a strong tooth, and provides easy control of the width of the land, which should be about $\frac{1}{32}$–$\frac{3}{64}$ in., depending upon the cutter or reamer. When the land becomes too wide from many sharpenings, the secondary clearance may be ground back to narrow the land to the correct width.

The proper clearance angle must be determined by experience. The following angles are recommended as a guide for general practice: ordinary low-carbon steel, 0–7°; hard steel, 2½–5°; steel castings, 6–7°; cast iron, fast feeds, 3–7°;

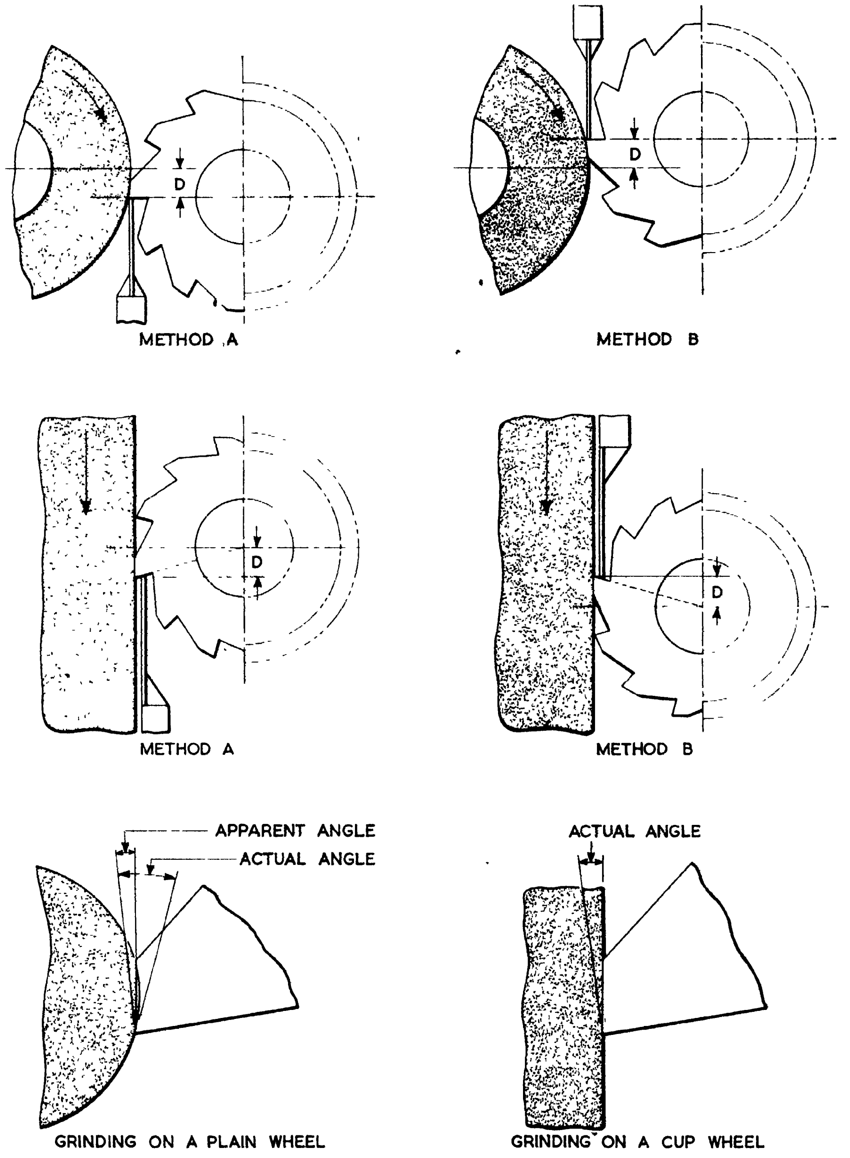


FIG. 9.—TWO METHODS OF GRINDING CUTTERS AND REAMERS, WITH PLAIN WHEELS AND CUP WHEELS

bronze, cast, 10–15°; tobin bronze, very tough, 4–7°; copper, 12–15°; aluminium, 10–12°. These angles are for average cutters. For large cutters they may be reduced slightly and for small cutters they may be increased.

PRODUCING THE CLEARANCE ANGLE.—The clearance angle is produced by properly locating the wheel, the cutter, and the tooth rest. There are several methods of accomplishing this, depending on the type of wheel used, the shape of the work, and the location of the tooth rest. The wheel may be either a plain wheel or a cup wheel. The work may be straight or tapered, or have straight or spiral teeth. The tooth rest may be located on the wheel head of the table.

When using a plain wheel, the clearance angle depends upon the diameter of the wheel, while with a cup wheel the diameter of the cutter is the determining factor. In general, the centre of the wheel and the work are brought into the same plane with the tip of the tooth rest by adjustments of the table or the wheel head, or both, and the tooth rest and cutter set to give the desired clearance. A centre gauge is used to line up the wheel cutter and tooth rest in the same place. In using a plain wheel, the cutter centre, the wheel centre, and the tooth rest (mounted on the table) are brought into the same plane using the centre gauge, and the tooth rest and table lowered or raised as shown in the illustration. In using a cup wheel, the cutter centre, the wheel centre, and the tooth rest (mounted on the wheel head) are brought into the same plane, and the wheel lowered or raised to give the required clearance. The distance the cutter or wheel is moved is represented by D in Fig. 9.

Some machines have dials on the work head which are graduated in degrees so that the setting of the cutter is quite simple. Others have a system of gears in the work head for producing the correct angle and automatically indexing each tooth as the grinding proceeds. Otherwise a calculation must be made or tables consulted to determine the setting of the tooth rest. Tables are given on page 458 for tooth-rest settings.

SETTING THE CUTTER.—To determine the setting of the cutter when using a plain wheel, multiply the clearance angle in degrees by the wheel diameter in inches by 0·0088. The result will be the distance in thousandths of an inch to raise or lower the cutter and tooth rest (mounted on table) to obtain the correct clearance. When using a cup wheel the setting is obtained by multiplying the clearance angle in degrees by the cutter diameter by 0·0088.

When the tooth rest is mounted on the wheel head:

Cup Wheel.—The wheel head is raised or lowered with no adjustment of the tooth rest.

Plain Wheel.—The wheel head is raised or lowered, but the tooth rest must be brought in line with the centre of the cutter.

When the tooth rest is mounted on the table:

Cup Wheel.—The wheel head is raised or lowered to avoid grinding on the tooth next to the one being sharpened, and the tooth rest raised or lowered the required amount.

Plain Wheel.—The wheel head is raised or lowered the required amount, but the tooth rest must be kept in line with the centre of the cutter.

(*Note.*—The movement between the wheel head and the table is only relative. The same effect is produced by raising or lowering the table and not moving the wheel head.)

The tooth rest is generally fastened to the table when grinding tapered cutters and reamers with straight teeth so as to produce the same clearance angle throughout the length of the tooth. The tooth rest must be fastened to the wheel head when grinding spiral milling cutters on centres, except when the set-up is such that the cutter is free to revolve and move longitudinally on the arbor, when it may be fastened on the table. When the tooth rest is fastened to the wheel head, the setting must be such that the cutter will pass off the wheel before passing off the tooth rest. In grinding spiral mills, the tooth rest must be set to follow the angle of the spiral.

Tables for Setting the Tooth Rest

PLAIN-WHEEL CLEARANCE TABLE.—For setting work centre and tooth rest below centre of wheel to obtain 5–7° clearance with wheels of different diameters when grinding on the periphery of the wheel:

Wheel Diameter (inches)	*D for 5° (inches)*	*D for 7° (inches)*	*Wheel Diameter (inches)*	*D for 5° (inches)*	*D for 7° (inches)*
2¼	0·099	0·139	4¼	0·187	0·262
2½	0·110	0·154	4½	0·198	0·277
2¾	0·121	0·170	4¾	0·209	0·292
3	0·132	0·185	5	0·220	0·308
3¼	0·143	0·200	5¼	0·231	0·324
3½	0·154	0·216	5½	0·242	0·339
3¾	0·165	0·231	5¾	0·253	0·354
4	0·176	0·246	6	0·340	0·370

Note.—If the grinding wheel is so large that it strikes the next tooth, a smaller wheel should be chosen, and the centres readjusted so as to be correct for the new diameter.

CUP-WHEEL CLEARANCE TABLE.—For setting tooth rest to obtain 5° and 7° clearance when grinding peripheral teeth of milling cutters with a cup wheel:

Cutter Diameter (inches)	*D. for 5° (inches)*	*D for 7° (inches)*	*Diameter (inches)*	*D for 5° (inches)*	*D for 7° (inches)*
½	0·022	0·031	2¾	0·121	0·170
¾	0·033	0·046	3	0·132	0·185
1	0·044	0·062	3½	0·154	0·216
1¼	0·055	0·077	4	0·176	0·246
1½	0·066	0·092	4½	0·198	0·277
1¾	0·077	0·108	5	0·220	0·308
2	0·088	0·123	5½	0·242	0·339
2¼	0·110	0·154	6	0·264	0·370

Grinding-wheel Speeds

Since different sizes of grinding wheels are used on tool and cutter grinders, it is important that the operator change the wheel r.p.m. when changing wheels to give the correct s.f.p.m. (peripheral speed) to the wheel. Wheel speed has a marked effect upon grinding-wheel action.

High speeds—wheel acts harder.

Low speeds—wheel acts softer.

Sometimes the operator can change the wheel speed to use wheels that are not suited to the work. Thus, if the wheel acts hard, the wheel speed may be reduced and vice versa.

The following formula may be used for calculating revolutions per minute (r.p.m.) and surface feet per minute (s.f.p.m.) or peripheral speed. The wheel diameter is in inches:

$$\text{s.f.p.m.} = \frac{3{\cdot}1416 \times \text{wheel diameter} \times \text{r.p.m.}}{12}$$

$$\text{r.p.m.} = \frac{12 \times \text{s.f.p.m.}}{3{\cdot}1416 \times \text{wheel diameter}}$$

SETTING UP TOOLS

Some recommended methods for setting up various tools for sharpening are given below.

Spiral Milling Cutter

The cutter should be mounted on a mandrel bar supported by footstock to prevent springing. The traverse may be obtained by moving the table or sliding the cutter on the cutter bar. Stops should be used so that the cutter will not run off the tooth rest. If table traverse is used, the tooth rest should be mounted on the wheel head, but if the cutter is moved on the cutter bar, the tooth rest may be mounted on the table, but it must be in line with the wheel face.

A cup wheel, Type 6 or 11, may be used, or a plain wheel, Type 1. When using the cup wheel, the wheel head should be swivelled slightly to provide clearance for the back side of the wheel.

Side Milling Cutter

The land should be $\frac{3}{64}$ in. and the clearance angle about 6°, with a secondary clearance of about 12°, which should be as small as possible and yet prevent drag of the heel of the tooth on the work. The sides of the teeth are ground to the same specifications. The cutter should be thinner at the inside edge of the blade than at the outside, or undercut slightly.

The cutter is held on a stud mounted in the workhead spindle, which is swivelled to the required angle for the clearance. A Type 6 or 11 cup wheel may be used or a Type 1 plain wheel. In the use of the plain wheel the cutter arbor should be in a horizontal position, and the wheel head raised or lowered to obtain the required clearance.

End Mill with Shank

The cutter shank is held in the taper of the work-head spindle to duplicate the working position of the cutter in the milling machine. End mills with shanks should never be located on centres for sharpening, because of the chance that the mill is sprung and so will be ground out of relation with the shank. The tooth rest is fastened to the table, and the work head is swivelled to procure the proper tooth clearance.

Large Face Mill

Large face mills should be mounted on the face-mill grinding attachment designed for the purpose. There are three operations in the grinding: the face of the teeth, the periphery of the teeth, and the corners of the teeth. The operations are similar to those of sharpening a shell end mill.

The corners of the teeth should be rounded off by first grinding a 45° flat and then angles of $22\frac{1}{2}$° on either side. The face edges should be $\frac{3}{16}$ in. wide and the remainder should be ground off at an angle of about 7° towards the centre of the cutter. If a true radius is desired, the radial grinding fixture may be used.

Helical Milling Cutter

The cutter is mounted on an arbor between centres. The tooth rest should be given a slight radius, and the cutting face of the wheel should be rounded to about $\frac{1}{16}$ in. radius, tapering back to the thickness of the wheel. The tooth rest is set so that its centre only will be in contact with the cutter at a point on the vertical line of the grinding wheel. The cutter, wheel, and tooth rest will be in contact at a common point, and the sharpening may proceed as with any milling cutter. A plain wheel Type 1 is used. There are other methods that may be used. The wheel face may be left square and the wheel head tilted slightly. In the method outlined above, allowance must be made in the tooth-rest setting for the angle of helix, so that the resulting clearance angle will be correct. With the same setting it can be seen that, as the angle of helix is increased, the clearance angle is reduced, so that in a theoretical case an angle of 90° would result in zero clearance.

Formed Cutters

Formed cutters, such as gear cutters, must not be ground on the diameter, but on the face of the cutting edges, in order that the form may not be disturbed. For this work, Type 12 wheels should be used. The face of the wheel must be on the radial centre line of the cutter.

(*Note.*—There are some exceptions to this rule, as in off-set cutters.)

Formed cutters may be ground on a cutter grinder or on a surface grinder with the proper fixtures. The tooth rest is on the back of the tooth being ground. The grinding is simple, but certain precautions must be observed:

(1) The wheel face must be in line with the centre of the cutter except for off-set cutters.

(2) The wheel face must be trued carefully with the diamond held in a fixture.

(3) The wheel must be located carefully with respect to the work.

It should be remembered that the grinding is done on the side of a dish wheel and that the feeds should be light.

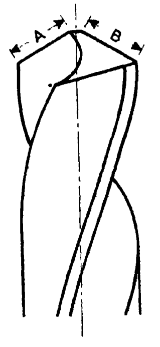


Fig. 10A.—Setting up drills
Length of cutting *A* must equal *B*.

Hobs

Hobs with straight teeth are ground in the same manner as formed cutters, radially on the faces of the teeth. It is especially important to preserve the profile of the teeth. For grinding hobs with spiral teeth, various methods are used. Several special attachments are made by the various machine-tool builders for setting up hobs for grinding. The method shown involves the use of a master form as a guide for the tooth rest. The master form is milled with the same spiral as the hob, and its accuracy determines the accuracy of the hob after grinding. The grinding wheel should be trued to a sharp edge and to the same angle as the cutter that milled the hob.

Fellows Gear Shaper Cutter

The sharpening of a Fellows spur-gear cutter is a plain grinding operation using the cylindrical grinding attachment. The cutter is held on a stud mounted in the work head, which is set to an angle of 5°, representing the rake of the cutter.

Reamers

The sharpening of a reamer is a far more delicate operation than sharpening a milling cutter, since much more accuracy is required. An error of a few

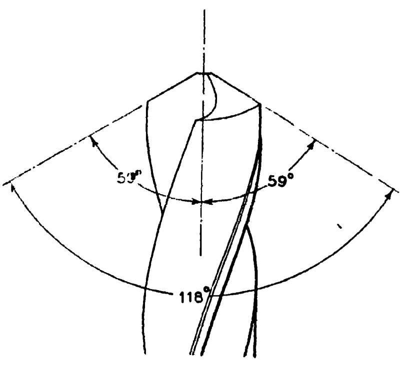


Fig. 10B.—Setting up drills
Correct angle of cutting lips: both lips must be at same angle.

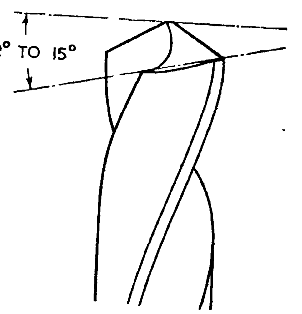


Fig. 10C.—Setting up drills
Correct clearance behind cutting edges.

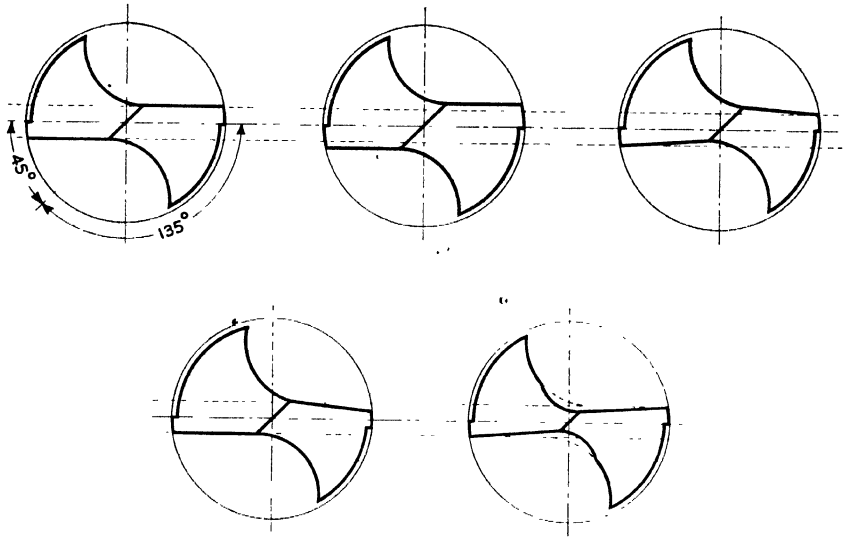


FIG. 11.—SOME COMMON DEFECTS IN DRILLS

Top (left to right): Correct clearance; web too thick; web out of centre
Bottom (left to right): Lips out of index; correct.

minutes in the clearance angle of a milling cutter does not perceptibly affect the results. The clearance angle of a reamer must be correct within a few minutes, or it will not operate satisfactorily.

Since a narrow land of constant width is required, two settings are necessary:

(1) Sharpening the reamer by grinding the proper clearance angle.

(2) Grinding off the heel of the blade to bring the land to the desired width.

Hand Reamer for Steel

Since the land for hand reamers for steel is only 0·006 in.–0·008 in. wide, the clearance can be ground cylindrically. The wheel must rotate so that the heel of the blade strikes the wheel first, or there will be no clearance. The slight spring in the reamer as it strikes the grinding wheel gives the clearance required.

The secondary clearance is ground in a manner similar to that employed in the grinding of a milling cutter.

Taper Reamers

More care must be used in grinding taper reamers because of two factors: the taper and the diameter. The land should not exceed $\frac{1}{32}$ in. wide. After grinding, a collar should be used for gauging, and a trial cut should be taken and the hole tested with a standard plug before the reamer is used. The cutting edges of a straight-tooth taper reamer must be straight to produce good results.

Usually, stoning the faces of the teeth is sufficient. However, if they are too irregular to be straightened in this manner, they may be ground with a cup or plain wheel.

Drills

More detailed notes on the grinding and super-finishing of reamers will be found in the section on "Fine Grinding and Finishing of Steel."

There are several requirements for a perfect working drill, lack of any one of which will result in high drilling costs and imperfect holes.

(1) *Equal Length of the Cutting Lips.*—Each lip must be exactly the same length. If they are of unequal length, the drill will produce oversize holes, one lip does all the cutting, and frequent sharpening is necessary. This results in high drill cost, since much metal is wasted during the frequent sharpenings.

(2) *Correct and Equal Angle of the Cutting Lips.*—The angle of the cutting lips must be exactly the same for each lip, usually 59°. The lip having the smaller angle will do no work, and again, the hole will be oversize and frequent grindings will be necessary.

(3) *Correct Clearance behind the Cutting Edges.*—Clearance is the relief behind the cutting edges. Without clearance the drill will not cut and with too much clearance the drill will dig in. It should be sufficient to ensure free cutting and yet not enough to weaken the cutting edge. It should increase gradually from the periphery to the centre of the drill. The clearance usually accepted as standard is 7° at the periphery, increasing towards the centre to such an extent that the angle of the web intersection on the lips will be 130–135° to the cutting edge. Unequal clearance will result in either chipping of the cutting edge or splitting of the drill.

(4) *Correct Thickness of the Web or Chisel Point.*—If the web is too thick, excessive power is required in drilling. If too thin, the point is weakened, so that it cannot withstand the thrust of drilling and the drill will fail. Since the web increases in thickness as the shank is approached, and as this central web does no cutting, it is important that it should not be thicker at the point than necessary. The point thinning, as this reduction in web thickness is called, should not be carried too far up the flute, and it is very important that the exact centre of the drill be maintained. In general the web thickness at the point should be about one-eighth of the thickness of the drill.

Modern maintenance demands accurate machine grinding of drills, for in no other way can they be ground accurately and so drill efficiently. A properly designed drill grinder will sharpen drills so that they will last twice as long, drill faster and more accurately than those ground by hand.

Some common defects found in drills are illustrated in Fig. 11.

There are two steps in the sharpening of a drill:

(1) Grind the cutting edge which develops the angle and clearance correctly.

(2) Thin the point (pointing) by offhand grinding a groove on each side of the flat between the cutting edges on a round-faced wheel, but better results

can be obtained on machines designed for the purpose having fixtures for holding the drill properly.

When drills become broken or cracked in the web, they may be salvaged by cutting off the broken section with a thin cut-off wheel and grinding the cutting edge as in sharpening. Mount the cut-off wheel on a tool or cutter grinder or cut-off machine.

Broaches (Backing Off)

A cup wheel is used for the backing-off operation to give the teeth the proper relief. A dish wheel is used for grinding cutter-bars, rectangular or square broaches on the face of the teeth. The swivel-head slide can be turned in a horizontal plane so that rectangular or square broaches with the teeth cut on an angle can be sharpened as easily as those with the teeth cut straight. The teeth are undercut 6–10° to give a curl to the chip. The chip cut by each tooth is 0·001 in.–0·007 in., depending upon the material being cut. The top clearance is 30°.

Broaches (Sharpening)

The method of sharpening round broaches is as follows: the broach is placed between the headstock and the tailstock centre with a lathe dog in the proper position for driving the broach. The swivel head is set at the proper cutting angle for grinding the teeth (0–12°), and the swivel head slide is then adjusted until the grinding wheel is exactly over the centre of broach. The grinding-wheel assembly is then lowered by the hand wheel until the grinding wheel is in proper position for grinding. Then by moving the table to bring the tooth of the broach in contact with the grinding wheel the tooth is sharpened in the correct manner.

When sharpening rectangular or polygon-type broaches the broach is held stationary by the dog to the faceplate, and the broach is indexed to the proper position by the use of the index plate on the headstock. The grinding wheel is lowered until it is in the right position, and is then moved back and forth across the cutting edge of the tooth. It is important to take only light cuts, to avoid burning the teeth, and that the wheel should be kept running freely by frequent dressing.

We are indebted to the Carborundum Co., Ltd., for supplying the information relating to grinding wheels and operational methods used in this article.

E. M.

CARBIDE-TIPPED TOOLS

In this article the notes on tool design and application are based upon information kindly supplied by A. C. Wickman, Ltd., Wimet Division, whilst the notes on tool tipping are based on information supplied by Protolite, Ltd.

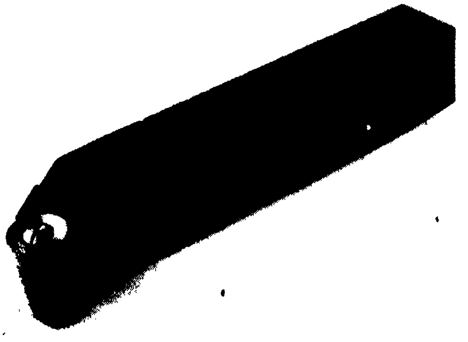
FIG. 1.—A "MITIA" GRADE TA-5 CARBIDE TOOL MACHINING A ROUGH FORGING OF HIGH-TENSILE ALLOY STEEL

The depth of cut averages ⅜ in. on the irregular scaly surface. (*Firth-Brown Tools, Ltd.*)

CARBIDE-TIPPED tools have during recent years acquired considerable importance in engineering production work.

There are several varieties available, e.g. tungsten carbide, tantalum tungsten carbide, and molybdenum titanium carbide. Each of these had properties rendering it most suited to certain types of work, and the specialists in the manufacture of carbide-tipped tools issue comprehensive data on the properties of the various branded tools which are now available on the market.

By the accurate use of tools of this type, the output of work obtainable from machine tools can often be increased by several hundred per cent. Tools of this type can also be successfully applied to the working of difficult materials, such as glass, marble, rock, rubber, and other substances which are not easily worked by the older type of cutting tools.



For lathe tools, milling cutters, metal saws, etc., the carbide material is prepared by a "sintering process" in the form of tips which are brazed in position on the tool proper, the latter being generally 0·05 per cent. carbon steel.

The method of tipping the tool with cemented tungsten carbide is described in the notes below, for which we are indebted to Protolite, Ltd.

FIG. 2 (*above*).—"WIMET" CLAMPTIP FOR TURNING HARD RUBBER

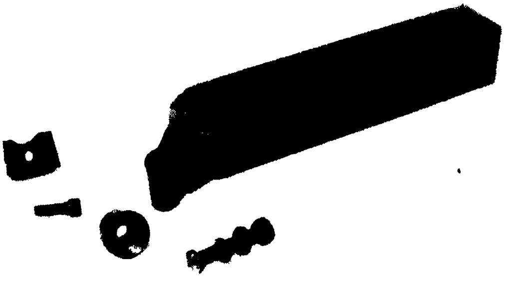


FIG. 3 (*right*).—THE SAME TOOL DISSEMBLED (*A. C. Wickman, Ltd.*)

FIG. 4 (*below*).—CINCINNATI MILLING MACHINE WITH INCLINABLE HEAD (*Protolite, Ltd.*)

TIPPING TOOLS WITH CEMENTED TUNGSTEN CARBIDE

The shank material, which should be 0·4–0·5 per cent. carbon steel, is cut to length, and then a tip seating has to be milled, using a milling machine having an inclinable head or an inclinable vice, so that the tip seat can be milled to the same angle as the top rake of the tool (Fig. 4). The tip seating should be $\frac{1}{32}$ in. longer and wider than the tip and the depth should be $\frac{1}{64}$ in. less than the thickness of the tip (Fig. 5). The tip should next be prepared by lightly grinding the surface against a suitable grinding wheel, such as a silicon carbide wheel of approximately 60–80 grit (Fig. 6). The tip should then be degreased by immersion in carbon tetrachloride or

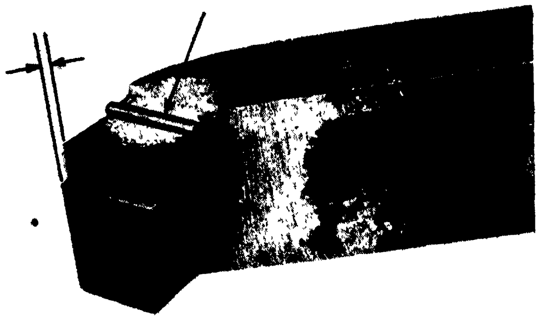


FIG. 5.—THE TIP IS PLACED INTO POSITION ON THE TIP SEAT OF THE TOOL, AND THE COPPER ADDED
(*Protolite, Ltd.*)

FIG. 6.—PREPARATION OF THE TIP BY LIGHTLY GRINDING AGAINST A GRINDING WHEEL
(*Protolite, Ltd.*)

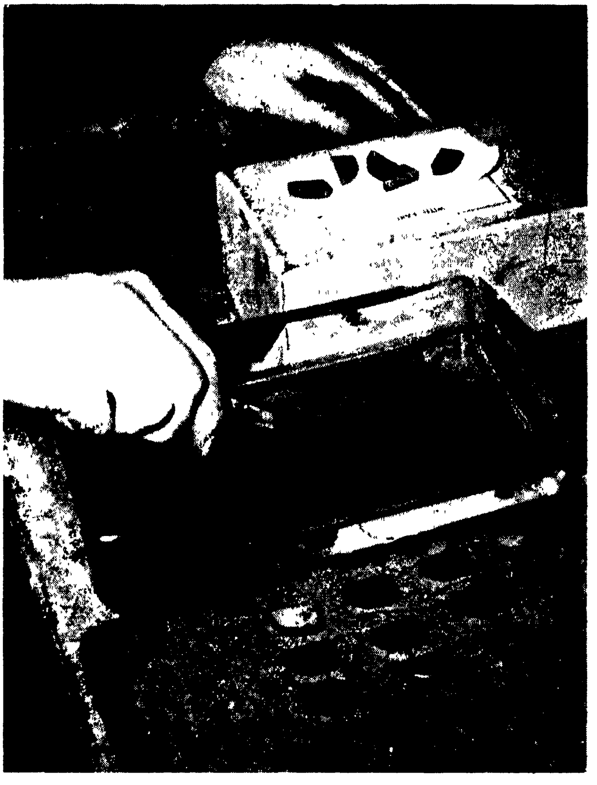


FIG. 7.—IMMERSION OF TIP IN CARBON TETRACHLORIDE (*Protolite, Ltd.*)

a similar degreaser (Fig. 7). After this, the tip must not be handled but always lifted in tweezers or small tongs. Everything is now ready for the brazing operation, which can be performed by using either one of the four following processes: torch brazing (Fig. 8); furnace brazing (Fig. 9); electric resistance tool brazing, or high-frequency brazing (Fig. 10).

Torch Brazing

When only small quantities of tools are to be brazed, a gas torch can be used, and the brazing medium should be either bronze sheet or wire. A con-

FIG. 8.—TORCH BRAZING TIPPED TOOLS (*Protolite, Ltd.*)

venient and economical method of preparing the flux is to mix borax powder with distilled water to form a smooth paste, which can then be applied. The shank to be tipped should be heated with the torch adjusted to give an excess of gas to prevent oxidation from taking place. Direct the flame on tò the shank and keep the flame moving to ensure even distribution (Fig. 11). When brazing heat is reached, the bronze sheet or wire will melt and the flame should be withdrawn and the tip pressed into position (Fig. 12). The tool should then be placed in a tray of powdered electrode carbon (Fig. 14), so that it may cool slowly away from atmospheric conditions.

FIG. 9.—FURNACE BRAZING TIPPED TOOLS
(*Protolite, Ltd.*)

FIG. 10.—HIGH-FREQUENCY BRAZING TIPPED TOOLS
(*Protolite, Ltd.*)

Furnace Brazing

In the furnace brazing method, copper sheet or wire can be used as a brazing medium; it is then necessary to use the preheating chamber, which should be kept at a temperature of 800° C., and the brazing chamber should be 1,200° C. The furnace must have a reducing atmosphere, which is obtained, in the case of a gas furnace, by using an excess of gas, and in the case of an electric furnace, by means of a gas curtain.

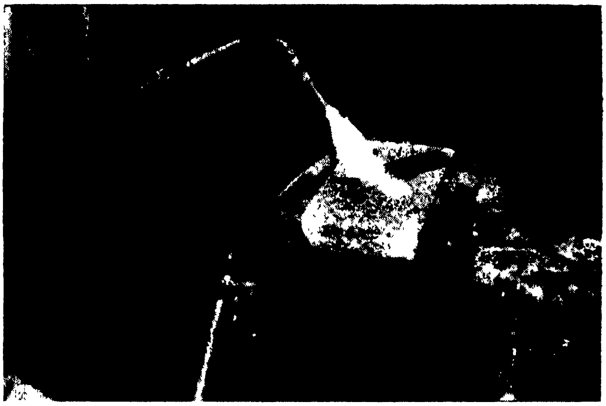


FIG. 11.—TORCH BRAZING

The flame is directed and kept moving on the shank of the tool to ensure even distribution. (*Protolite, Ltd.*)

Preheat the tool and tip in the cooler chamber until it reaches furnace heat. The tip should be placed on top of the shank to prevent thermal shock. Withdraw the tool, sprinkle the tip seating with borax, and quickly replace in the furnace. When the borax has fused or melted, remove tool and clean the tip seat with a wire brush. Place the tip in position on the tip seat, add copper (Fig. 5), sprinkle with borax, and place in hotter chamber (Fig. 9). When the copper has melted, remove tool from furnace, and press tip lightly but firmly into position (Fig. 13). Replace the tool in the cooler chamber to allow the

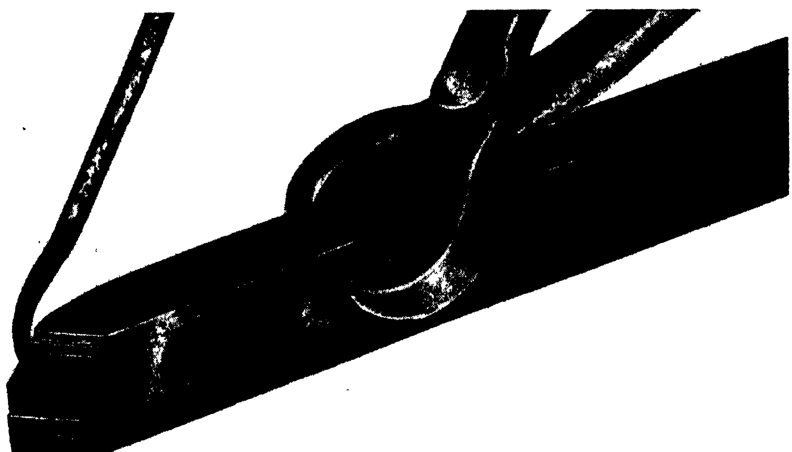


FIG. 12—TORCH BRAZING

Showing the tip being pressed into position after the flame has been withdrawn. (*Protolite, Ltd.*)

FIG. 13.—FURNACE BRAZING
Pressing the tip into position just after removal of the tool from the furnace. (*Protolite, Ltd.*)

copper to solidify, after which the tool should be placed in a tray of powdered electrode carbon.

Electric Resistance Tool Brazing

In this method the tool shank is clamped in a gunmetal vice, and the end to be tipped is firmly held against a copper head. The supply of electric current for shank and tip heating is pedal controlled; when the pedal is depressed, the current increases and the shank reaches brazing temperature. As the brazing medium melts, the pedal is released, and when a satisfactory braze has been made, the tool is removed from the vice. Otherwise this method is identical with the previous method.

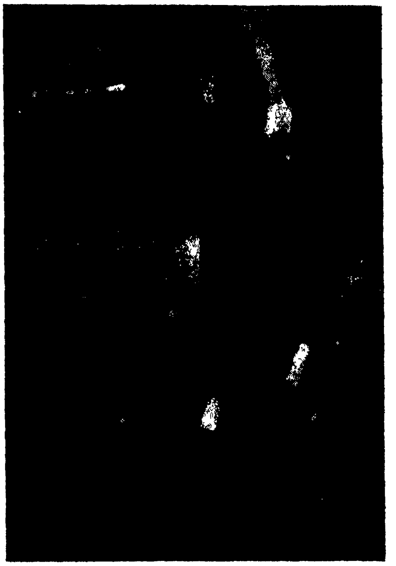


FIG. 14.—TORCH AND FURNACE BRAZING
Placing the tool in a tray of powdered electrode carbon to cool. (*Protolite, Ltd.*)

High-frequency Brazing

This method is very similar to electric resistance brazing, the only difference being that the tool to be tipped is placed into a heating coil and the current switched on. This method of brazing is only economical if large numbers of tools are to be tipped.

Clamptip Tools

An interesting development of the brazed-on or welded tool tip is a clamp-

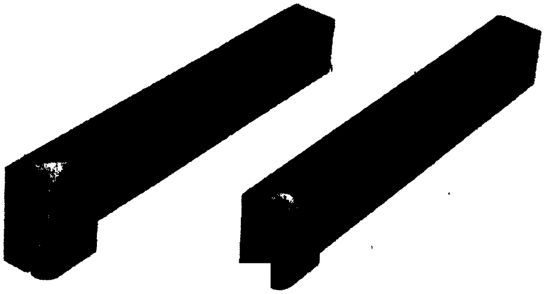


FIG. 15.—TYPICAL "WIMET" CLAMPTIP TOOLS (*A. C. Wickman, Ltd.*)

tip type, which has been recently introduced by Messrs. A. C. Wickman, Ltd., of Coventry.

Two typical examples are illustrated in Figs. 15 and 16, which show how the carbide tips, instead of being brazed to the shank, are clamped in specially designed toolholders. The clamping arrangements are simple, and provide a comparatively stress-free cutting tip, to which any desired top rake can be applied.

TOOL DESIGN

The form of the cutting tip on a cemented-carbide tool is of vital importance if the best results are to be achieved. The notes which follow are based upon information supplied by Messrs. A. C. Wickman, Ltd., the makers of "Wimet" tools, and the notes apply equally well to cemented-carbide tools in general.

Approach Angles

Where scaling is encountered, irrespective of the type of material, abrasion is invariably present to some degree, and adjustment of shape, and possibly rakes, is imperative in such cases. The major factor in the choice of the shape of a tool is that contributed by the immediate effect of chip pressure at the start of the cut; very often the end of a forging is rough and lumpy. In order to

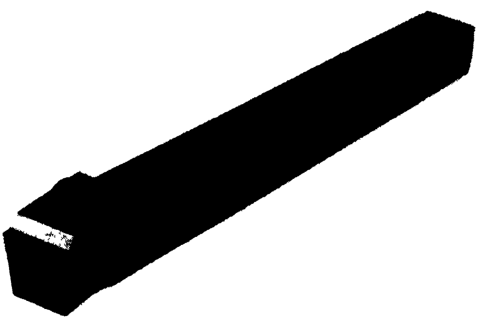


FIG. 16.—"WIMET" CLAMPTIP TOOL FOR TURNING CHILLED IRON ROLLS (*A. C. Wickman, Ltd.*)

obtain the lowest possible unit pressure at this point, the cutting edge should be as long as is practicable, and a tool with an approach angle up to 45° be chosen for this reason. It is possible, of course, to use a tool with a zero approach angle, and for a given depth of cut the chip pressure per unit of length will be at its maximum, as this shape of tool will produce a chip with a thickness equivalent to the feed per revolution.

A tool with an approach angle, cutting at the same depth of cut as before, and consequently requiring to resist the same total cutting pressure, has a lower cutting pressure per unit of length, and the chip is thinner, although of the same cross-sectional area as that produced by a tool with a zero approach angle.

The pressure in the direction of travel between the workpiece and the tool tends to break the point of the cutting tool, which should therefore be strengthened to resist this pressure and the plan trail angle should be reasonably small to avoid breakage at this particular spot. Similarly, where a facing cut is being taken, the conditions of shape should be adjusted to provide the maximum resistance to pressure. The cemented-carbide heavy-duty tool shown in

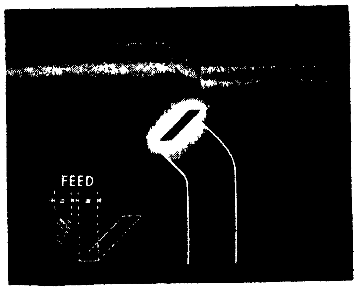


FIG. 17.—SHOWING HOW APPROACH ANGLE REDUCES CHIP THICKNESS WITH MAINTAINED METAL REMOVAL (*A. C. Wickman, Ltd.*)

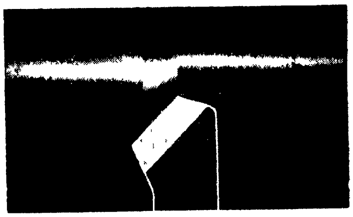
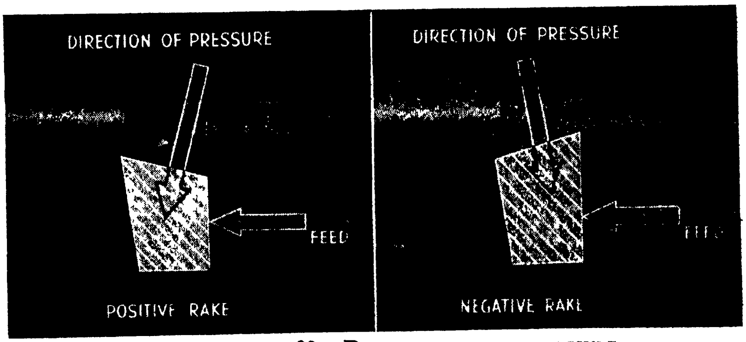


FIG. 18.—THIS TURNING AND FACING TOOL HAS REDUCED PLAIN TRAIL ANGLES TO OVERCOME POINT WEAKNESS (*A. C. Wickman, Ltd.*)



FIGS. 19 AND 20.—DIRECTION OF CHIP PRESSURE

Chip pressure with positive cutting rake tends to force the tool into the work, whilst negative cutting rakes direct pressure away from the workpiece (*A. C. Wickman, Ltd.*)

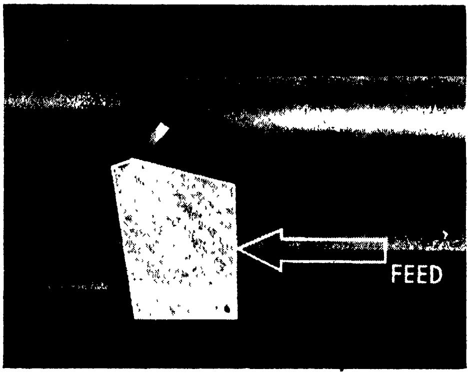


FIG. 21.—PRIMARY NEGATIVE CUTTING RAKE ADDED TO THE TOOL WITH POSITIVE SECONDARY RAKE (*A. C. Wickman, Ltd.*)

Fig. 18 is designed to fulfil all these conditions. It is capable of being used for both turning and facing cuts on rough forgings and castings, and provides maximum resistance to pressure in any operation.

Front to Back Rake

It is necessary to provide a shearing cut that will tend to guide the chip in a direction away from the workpiece, the lowest point of the cutting edge being at the point of the deepest cut (negative front to back). This principle applies to tools of any approach angle and offers the following advantages:

(*a*) The chip, in being parted from the parent metal, tends to curl away from that part of the workpiece already machined and consequently avoids damage to the finish from the chip in its flow across the surface of the tool.

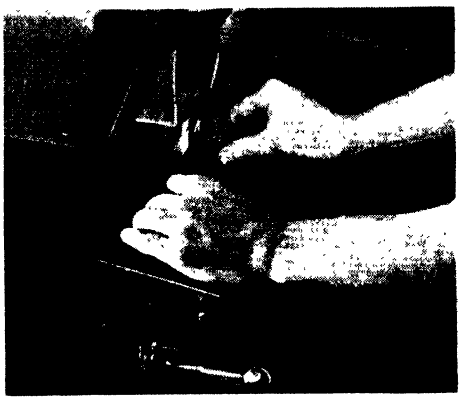


FIG. 22.—CORRECT WAY OF GRINDING A TOOL USING A SILICON CARBIDE WHEEL

Note the supply of coolant directed on to the tool. (*A. C. Wickman, Ltd.*)

(*b*) Any tendency for the point of the cutting tool to dig in is lessened, and results in reduced

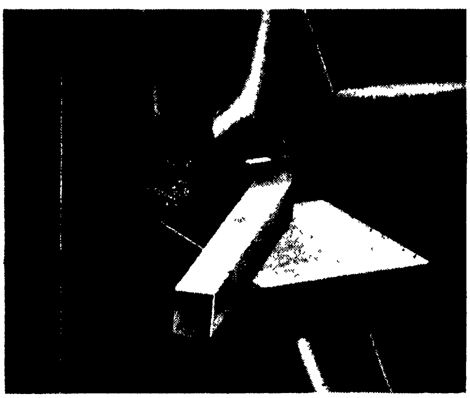


FIG. 22A.—INCORRECT WAY OF GRINDING THE TOOL

It is important that the periphery of the wheel should not be used, as the cutting edge of the tool would be undercut, thus removing support from the cutting point. (*A. C. Wickman, Ltd.*)

front clearance wear, as compared with a tool with the cutting edge higher at the point of deepest cut than at the outside of the job.

(*c*) Where an approach angle is employed, the shear cut allows a gradual build-up of pressure from the larger to the smaller diameter at the beginning of the cut.

Side Top Rake (or Cutting Rake)

Front to back rake should not be confused with side top rake (or cutting rake), which can be described as the angle that parts the chip from the workpiece (Figs. 19, 20, and 21). Generally, the greater the cutting pressure the flatter this rake should be.

FIG. 23.—LAPPING A CUTTING TOOL ON A "NEVEN" DIAMOND-IMPREGNATED METAL-BONDED WHEEL (*A. C. Wickman, Ltd.*)

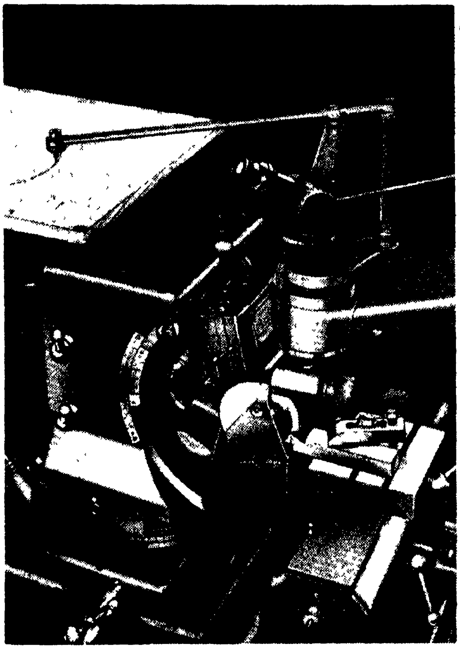


FIG. 24.—GRINDING A FORM TOOL, USING A WICKMAN OPTICAL PROFILE GRINDER

It is important to note that in all instances the wheel is rotating into the carbide tips, thus avoiding the removal of carbide particles.

The breakdown of a cutting edge almost invariably begins on the front clearance, and an appreciation of the effect of cutting pressure will assist in choosing an efficient side top rake to overcome tool failure through this cause. If the chip pressure were free from any fluctuation, then a standard rake might be possible for a great variety of materials being cut, but since variations in depth of cut and homogeneity of the material being cut may persist during the production of a chip, the effect is rather like that of a weight suspended on a spring, bearing in mind that the tool itself is, more often than not, a cantilever beam, and can deflect at the cutting point with every variation in the load applied to the cutting edge. This deflection causes a rub on the front clearances. If the side top rake were acute, then the pres-

sure applied by the chip would have a twisting effect causing additional rub on the front clearance. This twisting effect would be minimised if reduced rakes were employed under similar conditions.

The aim should be, therefore, to use a rake to give as obtuse a cutting angle as is practicable, without the excessive consumption of horse-power experienced with extreme negative rakes.

Primary and Secondary Rakes

It is becoming common practice to employ a system of primary and secondary cutting rakes in order to obtain the advantages of both negative and positive rakes (Fig. 21). In cutting a high chrome-nickel steel with a tensile strength of something over 70 tons per square inch, longer tool life is obtained with a negative top rake of about 3°, but since the horse-power consumption with this rake is high, arising out of the friction—under high pressure—between the chip and the surface of the tool, it is good practice to have an 8° positive secondary rake, leaving the cutting edge only with a primary negative rake of 3° This stiffens the cutting edge in such a way that the direction of pressure is outwards from the face being cut at the moment of shearing the chip, whilst the pressure between the chip and the cutting tool is relieved and the majority of the horse-power consumed to remove the chip, rather than be absorbed in friction. The width of this primary rake should normally be four times the feed.

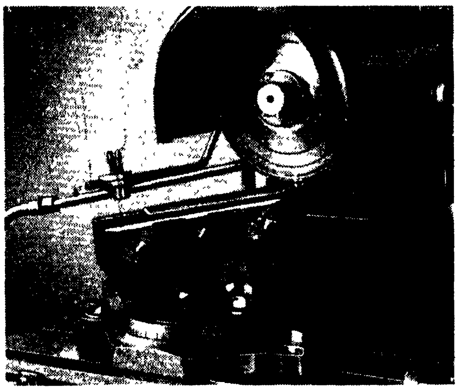


FIG. 25.—GRINDING A CHIP-BREAKER

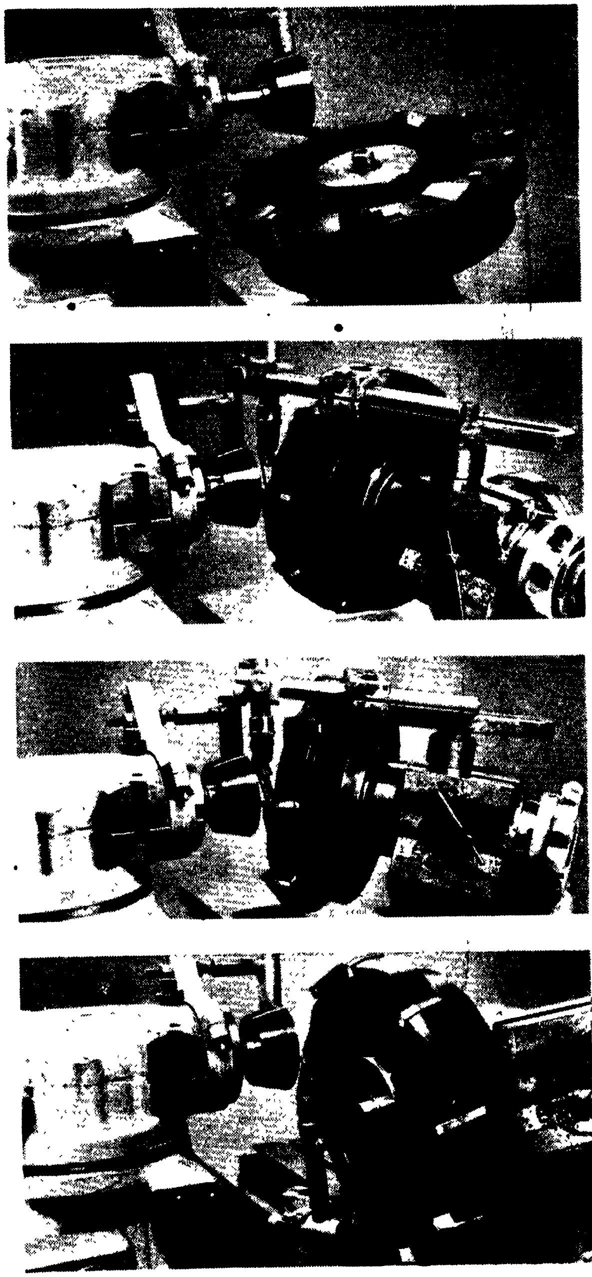
Chip-breakers should preserve the required cutting rake, and must therefore be ground on a suitable machine. (*A. C. Wickman, Ltd.*)

Many materials, however, require so little horse-power to part the chip that it is not necessary to use this principle of primary and secondary rakes. For cutting cast iron, low-carbon steels, and light alloys, positive rakes from 3° to 12° are quite practicable and economical. It is, however, desirable to use a reduced positive primary rake on medium and high-carbon steels. Materials in the bronze and brass classes are cut with best results when a zero primary rake is used.

METHOD OF USING CEMENTED-CARBIDE TOOLS

Having considered the principles upon which carbide tools should be designed, it is now desirable to discuss how to apply the tools in order to obtain the optimum performance of which they are capable.

FIG. 26.—RELAPPING A WICKMAN "MULTIMILL" CUTTER



(*a*) Lap the desired primary land $\frac{1}{32}$ in. wide to give the desired true rake. (This operation is omitted when a primary rake is not required.)

(*b*) Move the cutter over to 4° clearance angle and lap 15° bevel angle on outside diameter.

(*c*) Lap chamfer at 45°, allowing for clearance angle.

(*d*) Lap face of blade at 90° to bore of cutter, approximately $\frac{1}{32}$ in. wide and at 2° clearance. (This will give a parallel land.) Next lap " intake " or "dish."

Note.—It is important that a spring-loaded finger be utilised.

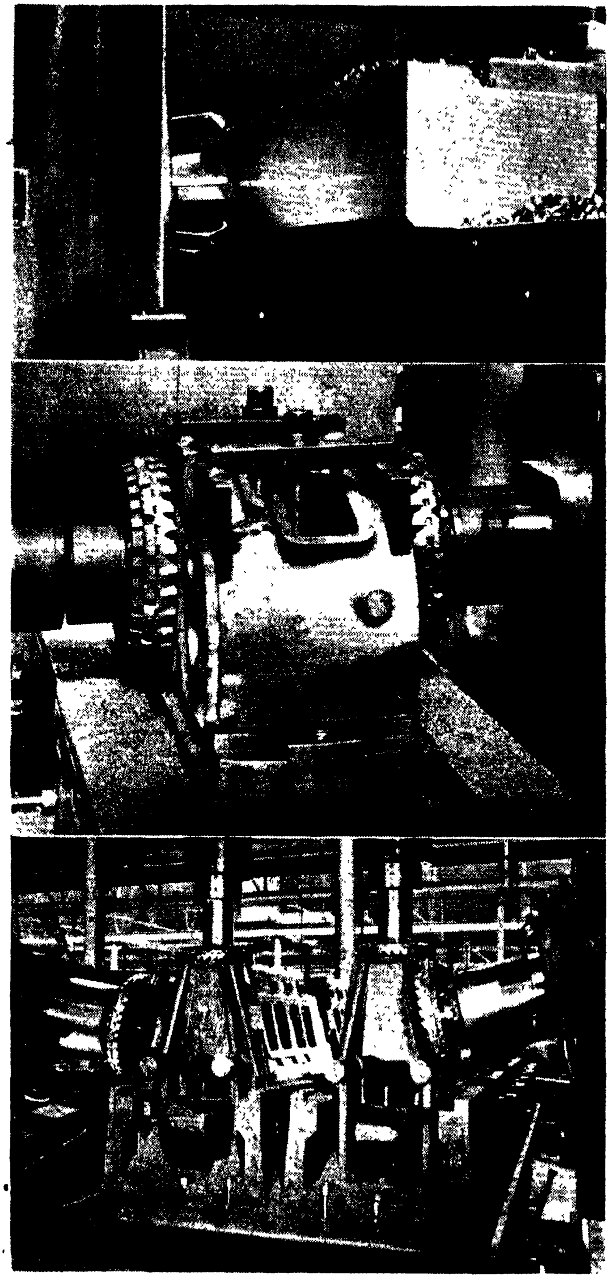


FIG. 27. — MILLING OPERATIONS

(*a*) A Wickman 6-in. diameter negative-rake milling cutter cutting 65-tons tensile steel.

(*b*) Wickman patent type "A" cutters milling a cast-iron gearcase. Speed, 200 ft. per minute. Feed, 6 in. per minute. Depth of cut, $\frac{3}{16}$ in. for roughing and $\frac{1}{32}$ in. for finishing. Between relaps 250 cases are milled.

(*c*) A Kendall and Gent machine equipped with four Wickman cutters milling four faces in one pass on cast-iron Diesel-engine crank-cases.

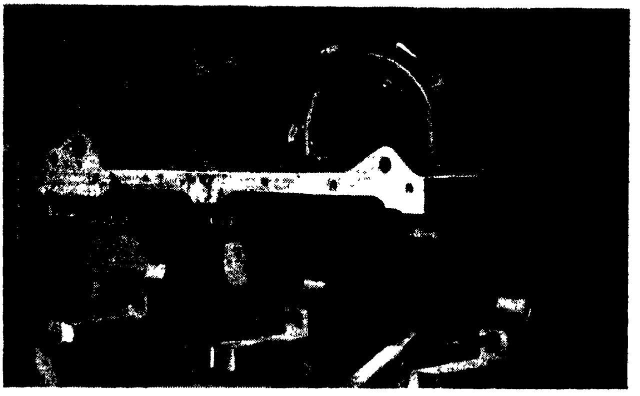


FIG. 28.—A WICKMAN "ALUMIL" CUTTER, USED IN CONJUNCTION WITH A FLYWHEEL MILLING ALUMINIUM ALLOY AT 60 IN. PER MINUTE

A table giving the recommended speeds and cutting rakes for "Wimet" carbide-tipped tools is given on pages 485 and 486.

Grinding Cemented Tungsten-carbide Tools

The successful use of cemented carbide tools depends on their correct grinding. It is always preferable to perform all grinding operations in a toolroom rather than allow each operator to grind his own tools.

We are indebted to Messrs. A. C. Wickman, Ltd., for the accompanying photographs (Figs. 22–30) illustrating toolroom methods of grinding cemented carbide tools.

The machine should preferably have reversible motors in order that right- and left-hand tools may be ground on the same wheels.

Setting the Tool

The tool should be set on the centre line of the work being machined.

If the "boat" type of toolholder is used, the tool must be set in a horizontal

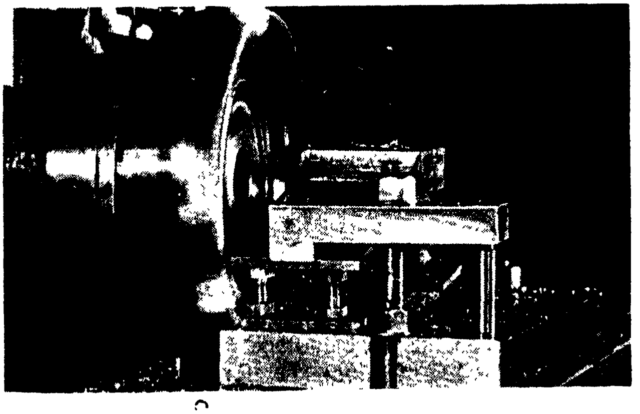


FIG. 29.—A WICKMAN FACE MILL, 10 IN. DIAMETER, 5° NEGATIVE HELIX AND RADIAL RAKES, MILLING AN AIRCRAFT ROOT-END-FITTING, 65 TONS TENSILE STEEL FORGING

Feed, 10 in. per minute. Speed, 600 ft. per minute. Number of components between relaps, 75.

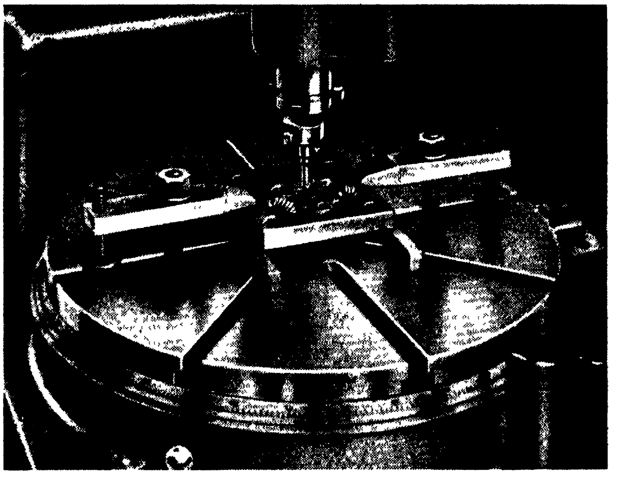


FIG. 30.—JIG BORING WITH A CARBIDE-TIPPED TOOL. (*A. C. Wickman, Ltd.*)

position. If the tool is tilted upwards, excessive front clearance will have to be ground so as to clear the work being machined. The top rake will then be increased, resulting in a weak cutting edge. If the tool is tilted downwards, the top rake will be decreased and excessive front clearance result (see Fig. 31).

The tool should be supported as far under the tip as circumstances permit and firmly clamped in position. Shock and vibration should be eliminated as far as conditions allow, and a shank section as large as possible used. Do not tighten holding screws on to the shank unless unavoidable. A metal strip placed on top of the tool will prevent distortion or lateral movement of the tool when tightening. It is easy to visualise the possible tightening down on the edge of an indentation already made in the shank by continual use, so causing the tool to move sideways. It is important that correct top rakes be used for the particular material being machined, and the clearance angles should be small (4–5° will generally be found adequate).

Feeds

In determining feed rates, it is as well to consider just what happens when the tool enters the cut. Immediately the cutting edge touches the workpiece, spring in the tool and the elastic resistance to penetration of the tool into the workpiece causes an initial rub, until the power input to the machine forces a penetration of the cutting edge into the workpiece. Gradually, but very quickly of course, the tool is able to take the full feed, but during this initial rubbing prior to penetration of the cutting edge into the workpiece, damage has been done to the front clearance. That is why a tool producing components with a relatively short cut cannot produce the same footage of cutting as a tool producing a much longer job. The life of a tool, therefore, is determined by

TOOL CORRECTLY SET: HORIZONTAL AND ON CENTRE

TOOL TILTED: INSUFFICIENT FRONT CLEARANCE, EXCESSIVE TOP RAKE

TOOL TILTED: REDUCED TOP RAKE, EXCESSIVE FRONT CLEARANCE

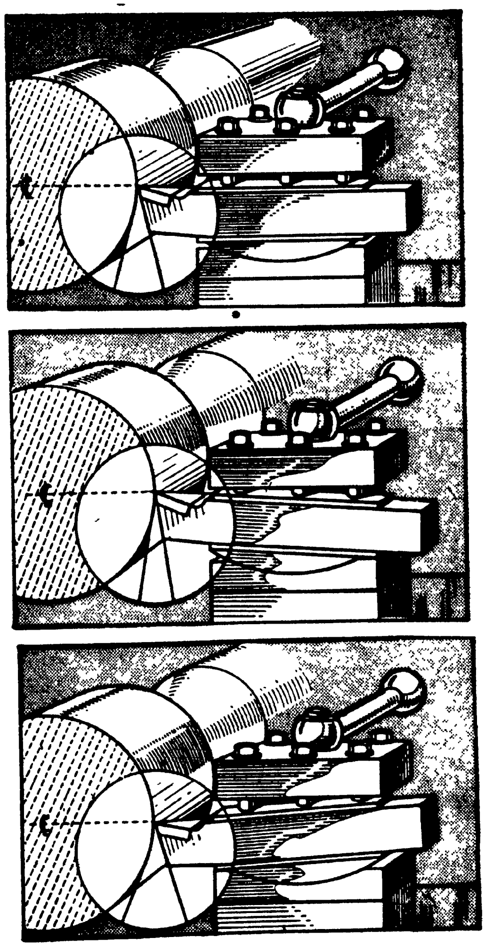


FIG. 31 —SETTING THE TOOL

The tool should be set on the centre line of the work being machined.
(*A. C. Wickman & Co., Ltd.*)

FIG. 32.—SECONDARY CLEARANCE

The use of secondary relief angles under the tip will increase wheel life.

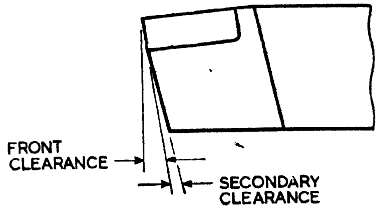


FIG. 33.—PRECISE TOOL ANGLES REQUIRE MACHINE GRINDING (*A. C. Wickman, Ltd.*)

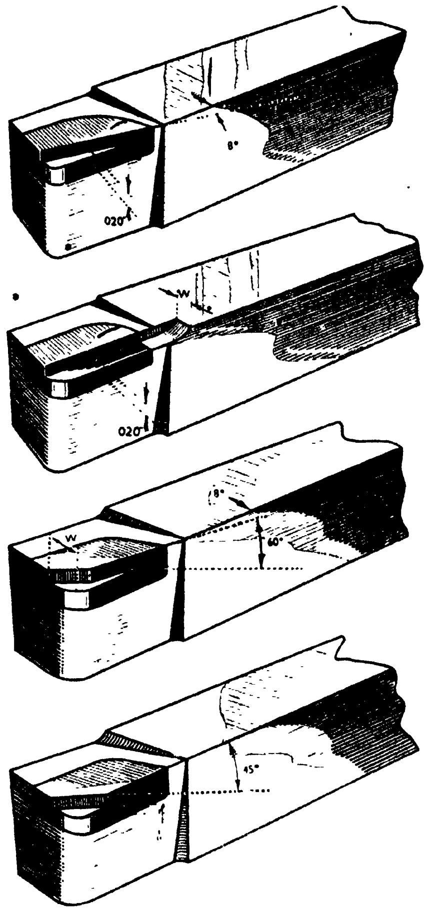
the number of starting cuts during its life, or the number of components rather than the amount of surface area machined.

Materials vary in their characteristic resistance to entry of the tool. Some steels, for example, will allow penetration when the feed is only about 0·0005 in., whilst others, such as certain aluminium alloys, will require a minimum feed of 0·005 in. to avoid the tool being used to rub the material away. The feed per revolution of a lathe or the feed per tooth of a milling cutter should therefore be determined on this basis, and the figure should never be less than 0·0005 in. on carbon steels, for example. It is rare, fortunately, that the minimum feed is necessary, but where such conditions must be met, it is desirable to lap a fine edge on a cemented-carbide tool and to observe at what point the actual chip ceases to be produced and the metal is removed in the form of dust. At this stage the feed is less than the minimum desirable.

FIG. 34.—OFFHAND GRINDING IS SUITABLE FOR MOST TURNING TOOLS (*A. C. Wickman, Ltd*)

The finer cutting operations, such as jig boring, precision auto-tooling, and reaming, often require to have feed rates determined in such a way that high finish is obtained and feeds are often reduced to the economic minimum in order to reduce the cutting pressures to the lowest possible figure, so that the finish obtained on the workpiece is not affected by intermittent deflection of the tool during cut.

Another practice in general use is to provide a trailing edge on tools of this type, overlapping



1. For general use and heavy cuts.

2. For use when depth of cut varies as with rough forgings.

3. For use with large nose radius.
W = 1½ × Rad.

4. For finishing cuts with maximum depth of $\frac{1}{32}$".

FIG. 35.—EXAMPLES OF GENERAL TYPES OF CHIP-BREAKERS

A small radius should be produced at the root of the chip-breaker. The examples above show the application of chip-breakers to tools with zero approach angle. The same principles apply to tools of any approach angle. (*A. C. Wickman, Ltd.*)

three feed distances to smooth out the cut marks and to improve the finish produced.

It will, of course, be recognised that this practice produces the rubbing effect previously mentioned, where the feed and/or depth of cut is below the economic minimum, and some sacrifice of tool life is normally expected when this practice is followed.

Speeds

Every material has an optimum cutting speed that will give the maximum tool life for the maximum metal removal rate, and this is determined by taking a check cut at various speeds, and the lowest speed which shows sudden improvement in finish is that which should be used for normal machining operations. The speed can be increased to the maximum given in the manufacturer's tables for finishing, as it is not so necessary in finishing cuts to consider the effect of cutting pressures.

Little can be done about obtaining a uniform finish throughout a facing cut unless a stepless speed variation drive is employed in the machine being used; although the speed can be maintained at a more uniform rate by previously determining at what diameters the revolutions per minute should be reduced.

Generally, on internal work where single-point tools are used, cutting speeds of about two-thirds of those used for turning are employed. This is done because a boring tool is not as well supported below the cutting edge as is a turning tool, and is consequently not able to withstand the same cutting pressures. Feeds should be reduced, bearing in mind the need to avoid rubbing on cutting edge, which is the major cause of cutting edge wear.

If a cutting edge is badly broken, or if it is desired to alter the shape of a tool, it is recommended that a green grit wheel be used. For grinding a worn cutting edge, a finishing wheel is suitable.

The peripheral speed of the wheels should be approximately 5,000 ft. per minute and a copious supply of water used. Never plunge a hot tool into water to cool, as cracking of the tip will result.

The cutting edge of a cemented carbide tool after grinding on a silicon carbide grinding wheel is seen under a microscope to be very uneven. To bring this uneven edge to its required state for efficient cutting, the tool must be diamond lapped.

Secondary Clearance

Wheel life can be increased by the use of secondary relief angles under the tip to allow for the grinding or lapping of the tip only, and not the shank material, which would quickly load the wheel (Fig. 32).

It is permissible to grind on the periphery of the wheel when rough grinding; finish grinding and lapping, however, should always be performed on the face of recessed or cup wheels. When tools are ground on the periphery of grinding wheels, a hollow-ground effect is produced, and this weakens the cutting edge. The surface speed of the grinding wheel is also reduced with wheel wear.

The use of grinding gauges or templates to ensure that rakes and angles of tools are maintained will be found advantageous. It will be found most economical to have a centralised grinding department rather than individual methods.

When a tool needs regrinding it should be immediately taken from the toolbox and reground. It is a mistake to think that economy is being practised by machining an extra two or three components with a dull tool. More than likely

RECOMMENDED SPEEDS AND CUTTING RAKES FOR GENERAL MACHINING

STEELS

Material	Wimet Grade	Turning Ft. per min. Rough	Turning Ft. per min. Finish	Boring Ft. per min. Rough	Boring Ft. per min. Finish	Reaming Ft. per min.	Planing Ft. per min. Rough	Planing Ft. per min. Finish	Milling Ft. per min. Rough	Milling Ft. per min. Finish	Cutting Rake	Metal Removal Efficiency Cu. in. per h.p. per min.
0·15 per cent. carbon forgings and bar	"XX"	750	1,000	500	750	40	—	—	750	1,000	+8°	0·93
	"X8"	600	900	400	600	40	300	300	600	900	+8°	0·93
	"S58"	200	300	150	200	40	200	200	200	300	+15°	0·93
0·3–0·4 per cent. carbon forgings and bar	"XX"	680	850	450	600	40	—	—	680	850	+3°	0·85
	"X8"	550	750	350	550	40	300	300	550	750	+8°	0·85
	"S58"	200	300	150	200	40	200	200	200	300	+15°	0·85
0·3–0·4 per cent carbon castings	"XX"	350	420	200	300	35	200	250	350	420	−4	0·70
	"X8"	300	380	200	260	35	200	250	300	380	2°	0·70
	"NS"	250	380	180	260	35	120	250	250	380	2°	0·70
0·7 per cent. carbon forgings and bar	"XX"	280	400	150	250	35	250	300	280	400	−2°	0·72
	"X8"	250	350	150	220	35	250	300	250	350	0	0·72
	"S58"	100	120	70	80	35	100	120	100	120	+8°	0·72
3 per cent. nickel	"XX"	350	420	200	300	40	200	250	350	420	+3°	0·60
	"X8"	300	380	200	260	40	200	250	300	380	+3°	0·60
	"S58"	120	150	80	100	40	120	150	120	150	+15°	0·60
1 per cent. chrome (55 tons) forgings and bar	"XX"	450	550	300	400	40	—	—	450	500	+3°	0·70
	"X8"	350	450	250	300	40	250	300	350	450	+3°	0·70
	"S58"	150	180	100	120	40	150	180	150	180	+8°	0·70
Nickel chrome (65–75 tons) forgings and bar	"XX"	400	550	300	400	40	—	—	450	500	0°	0·65
	"X8"	300	450	250	300	40	250	300	350	450	+3°	0·65
	"S58"	120	150	80	100	40	120	150	120	150	+8°	0·65
Nickel chrome (100 tons) forgings and bar	"XX"	225	250	150	150	30	525	225	225	250	2°	0·60
	"X8"	180	200	120	140	30	180	200	180	200	2°	0·60
1 per cent. chrome manganese (normalised)	"XX"	400	500	300	350	40	300	300	400	500	0°	0·70
	"X8"	300	400	200	280	40	300	300	300	400	+3°	0·70
	"S58"	150	180	100	120	40	150	180	150	180	+8°	0·70
Stainless steels, forgings and bar	"S58"	90	120	90	120	25	90	120	90	120	+15°	0·50
Stainless steel castings	"X8"	Up to 100		Up to 100		25	Up to 100		Up to 100		+8°	0·40
	"S58"	Up to 100		Up to 100		25	Up to 100		Up to 100		+8°	0·40

Reaming speeds bear no relationship with boring speeds or with metal-removal efficiency rates. As it is necessary to ensure roundness of holes, low speeds with increased feeds induce steadying influence.

RECOMMENDED SPEEDS AND CUTTING RAKES FOR GENERAL MACHINING

Irons and Non-ferrous Materials

Material	Wimet Grade	Turning Ft. per min. Rough	Turning Ft. per min. Finish	Boring Ft. per min. Rough	Boring Ft. per min. Finish	Reaming Ft. per min.	Planing Ft. per min. Rough	Planing Ft. per min. Finish	Milling Ft. per min. Rough	Milling Ft. per min. Finish	Cutting Rake	Metal Removal Efficiency Cu. in. per h.p. per min.
Cast iron. 200 Brinell	"N" or "H"	180–250	300–400	180	250	35	180–200	300	250	400	+3°	1·25
Spun-iron castings	"N" or "H"	135–200	200–300	135	200	30	100	200	135–200	200–300	+3°	1·25
Nickel iron (1 per cent. Ni)	"N" or "H"	150–200	200–300	120	200	30	150	200	150–200	200–300	+3°	1·25
Nickel iron (10 per cent. Ni)	"N" or "H"	25–35	25–45	15	30	10	25	30	25	45	−2°	1·00
Malleable iron (high steel content)	"XX"	300–350	400–500	200	350	—	—	—	—	—	0°	0·9
Malleable iron (high-steel content)	"X8"	300–350	400–500	200	350	—	300	300	300	300	+3°	0·9
Malleable iron (low steel content)	"N" or "H"	180–250	350–400	180	250	30	180–200	300	250	400	+3°	1·25
Copper	"N" or "H"	3,000	10,000	3,000	10,000	60	—	—	3,000	10,000	+15°–+30°	3·00
Cupro nickel	"N" or "H"	350–500	400–600	300	400	40	300	300	500	600	+8°–+15°	2·00
Soft brass	"N" or "H"	1,000	1,500	800	1,200	60	—	—	1,000	1,500	+3°	1·5
Cast brass	"N" or "H"	400–600	500–1,000	400	600	40	300	300	600	1,000	0°–+3°	1·2
Phosphor bronze	"N" or "H"	400–600	500–1,000	400	600	40	300	300	1,000	1,000	0°–+3°	1·15
Aluminium bronze	"N" or "H"	400–600	500–1,000	400	600	40	300	300	600	1,000	0°–+3°	1·13
Manganese bronze	"N" or "H"	400–600	500–1,000	400	600	40	300	300	600	1,000	0°–+3°	1·01
Aluminium alloys	"X8," "N" or "H"	Up to 1,000 unlimited		Up to 1,000 unlimited		60	Up to 300 unlimited		Up to 1,000 unlimited		+8° +8°–+15°	6·00 6·00
Plastics	"N" or "H"	200	600	300	800	—	200	600	400	600	0°–+8°	—
Hard rubber	"N" or "H"	600	800	600	800	—	—	—	800	800	+8°–+15°	—
Medium rubber	"N" or "H"	400	400	400	400	—	—	—	400	400	+30°–+45°	—

Clearance angles are standard at 4°–6°, and for cutting plastic materials these will require to be increased by an additional 2°–4°.

COMPARISON CHART OF SINTERED CARBIDES IN ENGLAND

(*Prepared by "Industrial Diamond Review.*")

Material	*Characteristics and Uses*	*ALLENITE* *Edgar Allen & Co., Ltd.*	*ANNOLLOY* *F. C. Annett & Co., Ltd.*	*ARDOLOY* *Alfred Herbert, Ltd.*	*BALFALLOY* *Arthur Balfour*	*CUTANIT* *Metro-Cutanit*
Cast-iron, non-ferrous, and non-metallic materials.	Very hard and abrasion-resistant for light finishing cuts to close tolerances and fine boring.	CH	H1 H2	<u>1A179</u>	H.1 or FS.2	ICC
	High wear resistance combined with toughness. Designed for production machining to close limits.	N	F1	<u>1A179</u>	H	I
	Tough, shock-resistant grade for general-purpose machining and heavy duty, including intermittent cuts; gives dependable performance.	TN	F2	<u>2A</u>	HL	M or O
Steel and steel alloys.	Exceptionally hard and abrasion-resistant for high-speed finishing cuts at close tolerances. Less shock-resistant than other grades.	ES	S1	S100	HA	<u>S</u>
	Wear-resistant and tough. General-purpose applications for all types of steel. Light intermittent cuts.	AS	S2	<u>S200</u>	BZ	<u>T</u>
	Very tough, shock- and crater-resistant, suitable for slow speeds and deep cuts; for large steel pieces; withstands severe interrupted cuts.	TS	S3	<u>S48</u>	HD	R

Underlining denotes best comparison.

(*Reproduced by courtesy of "Industrial Diamond Review.*")

COMPARISON CHART OF SINTERED CARBIDES IN ENGLAND—*continued*

(*Prepared by "Industrial Diamond Review."*)

Material	Characteristics and Uses	*ESCALOY* *English Steel Corp.*	*HYDRALOY* *Hall & Pickles*	*AJKO* *A. Johnson & Co., Ltd.*	*MITIA* *Firth-Brown Tools, Ltd.*	*OSBORNITE* *Samuel Osborn & Co.*
Cast-iron, non-ferrous, and non-metallic materials.	Very hard and abrasion-resistant for light finishing cuts to close tolerances and fine boring.	$\underline{\text{A1}}$	HR/CA	HB	C	CR
	High wear resistance combined with toughness. Designed for production machining to close limits.	$\underline{\text{A1}}$	GP/CA	B	B	IC
	Tough, shock-resistant grade for general-purpose machining and heavy duty, including intermittent cuts; gives dependable performance.	L1	HPO/HPO2	AJ	A	RI
Steel and steel alloys.	Exceptionally hard and abrasion-resistant for high-speed finishing cuts at close tolerances. Less shock-resistant than other grades.	S	FM	STJ or SO	TE	FF
	Wear-resistant and tough. General-purpose applications for all types of steel. Light intermittent cuts.	$\underline{\text{S}}$	RSN/NQ	ST	TTA	HT
	Very tough, shock- and crater-resistant, suitable for slow speeds and deep cuts; for large steel pieces; withstands severe interrupted cuts.	$\underline{\text{C}}$	RIC	SS	TA5	RW

Underlining denotes best comparison.

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COMPARISON CHART OF SINTERED CARBIDES IN ENGLAND—*continued*

(Prepared by Industrial Diamond Reveview.")

Material	*Characteristics and Uses*	*PERPRO Production Tool Alloy*	*PROLITE Protolite, Ltd.*	*TECO R. C. McLeod, Ltd.*	*VERALOY Veraloy Products*	*WIMET A. C. Wickman, Ltd.*
Cast-iron, non-ferrous, and non-metallic materials.	Very hard and abrasion-resistant for light finishing cuts to close tolerances and fine boring.	AU	24A	C144 B	B1	H
	High wear resistance combined with toughness. Designed for production machining to close limits.	AU	1C 21A	C B	B1	N
	Tough, shock-resistant grade for general-purpose machining and heavy duty, including intermittent cuts; gives dependable performance.	AS	15A	A AS	U	G
Steel and steel alloys.	Exceptionally hard and abrasion-resistant for high-speed finishing cuts at close tolerances. Less shock-resistant than other grades.	PB	8K 4T	F E	SH2	XX XX7
	Wear-resistant and tough. General-purpose applications for all types of steel. Light intermittent cuts.	PA	6W 14K	EE E	SH2 S65	X8
	Very tough, shock- and crater-resistant, suitable for slow speeds and deep cuts; for large steel pieces; withstands severe interrupted cuts.	PC	2W	SN	S65 U	S58

Underlining denotes best comparison.

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it will be found that the time spent in machining these extra components will be lost by additional grinding time necessary to recondition a badly worn tool.

Tools which require a cutting edge to be maintained to precision dimensions, however, are often reconditioned on tool and cutter grinders, and in these cases, because the cutting rate of the diamond wheel can be controlled, it is good practice to use a bakelite-bonded diamond-impregnated wheel.

Chip-breakers

The characteristics of most metal turning usually result in the production of a continuous chip when machining at speeds in excess of 150 ft. per minute. For easy chip disposal, and to protect the operator from injury, the continuous chip must either be curled or broken into short lengths.

Frequently this chip-breaking can be carried out by increasing the feed to obtain a cross-section area (feed × depth of cut) which breaks easily. Another means is to apply rapid cooling at high velocity. Alternatively, there is the chip-breaker formed or ground into the tip itself.

Chip-breakers vary in width, depending upon the depth of cut and feed. Some examples of general types of chip-breakers are shown in Fig. 35.

Before commencing a cut on a steel application, the extremely sharp edge of the tool should be stoned by means of a hand lap or carborundum stick. To commence to cut with a cemented carbide tool having a "razor edge" would be detrimental, owing to the extreme hardness of the metal. In addition, chips removed from the material being cut would quickly break down an extremely sharp edge and so destroy any desired finish. The stoning of the cutting edge should be carried out lightly and with care, as too much blunting will result in undue cutting pressure.

Coolant

It is dangerous to use a drip coolant when cutting with cemented carbide-tipped tools, as the tip would then be subjected to varying temperatures. Hot and cold spots so produced cause hairline cracks in the tip. If it is desired to use coolant, then an ample supply is necessary, but dry cutting is quite satisfactory and recommended, provided no danger exists of moisture being present from a previous operation.

Metals of the character of aluminium and aluminium alloys can be worked with a fluid of low viscosity, such as paraffin or turpentine, whereas steels require a fluid of high viscosity when a lubricant is used. For a highly polished finish in the machining of copper at high speeds, turpentine will be found most suitable. Paraffin is not recommended, as it causes a blotchy finish.

In the forming of high-tensile steels, a mixture of half-pint of turpentine to a tablespoonful of sulphur will give good results.

In fine boring steels, soluble oil is recommended as a lubricant; cutting oil allows small chips to cling to the cutting edge of the tool and even to the walls of the hole itself, so causing scratches.

E. M.

PLANING AND SHAPING

THE difference in principle between planing and shaping operations is that the work travels in the first case, the tool in the second. There are some exceptions, but generally this rule holds good.

The planer can take very long and wide cuts, over single and multiple pieces. The shaper is more handy for all sorts of moderate-length tooling and intricate forms, where the planer would be out of the question for quick manipulation. Larger castings and forgings can be held before a shaper ram for detailed cutting. The same kinds of standard tools are used in each, with occasional special forms.

Multiple Cutting

Multiple cutting is performed on the planer by boxes on the cross-rail and uprights; on the shaper by fitting two or three heads along a single bed.

Operative efficiency has been much improved recently by electric driving and control, and by the use of cemented-carbide tools.

PLANING PRACTICE

Planing machines have variable cutting speeds provided to suit different materials, acceleration between gaps in the work, high-speed return, control by pendant switch for speeds and feeds, electric feeding devices, and magnetic tool lifters. A further time-saving idea appears in the "tandem" machines, having a very long bed and two tables. Whilst one is working the other is out at the end being stripped and reloaded, so that operation is never held up.

Methods of Holding Work

A very secure hold is essential, because of the shocks of cutting and the number of tools in action. The usual bolts and clamps common on most machine tools require to be supplemented by positive resistance against skidding. This is furnished by end stops (Fig. 1) and often side ones, plain pegs fitting in reamed holes in the table, pegs with screws to adjust touching the work, bars laid across the pegs to form a continuous resistance, and angle plates, quite high for tall objects liable to overset. Props of plain or screw type are strutted from low angle plates, or the ledges at the table ends, to prevent tilting. Angle plates, ordinary or special, hold shapes that will not rest well on the table alone, or require accurate location by a vertical face.

Packing Up

It is often a troublesome matter to support pieces steadily and without risk of displacement. Simple forms which will rest equally on parallel strips are

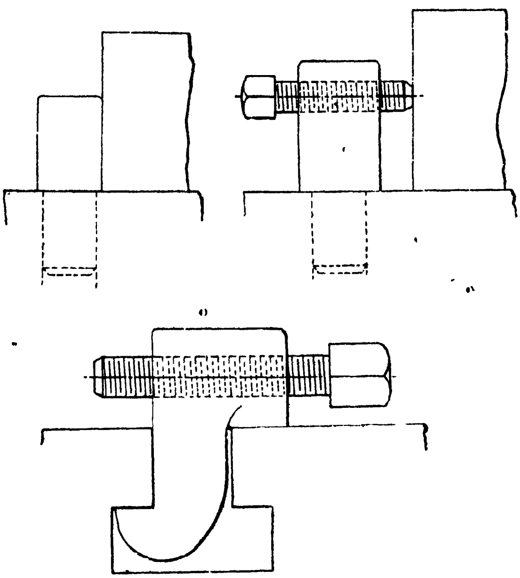


Fig. 1.—End or side stops which prevent work from skidding on planing machine table

easy, but when several different heights need packing up and the clamps applied, there is, first, difficulty in levelling and, second, in holding down without distortion. The necessary adjustments must be effected by wedges, thin strips or screws, usually in jacks which can be located anywhere, but sometimes tapped into cradles or fixtures carrying repetition subjects. Clamps must not be set over ledges or other portions which do not rest solidly on packing, or deflection is bound to occur. In cases where there is likelihood of springing, a roughing cut is taken and the clamps are slightly loosened, thus releasing the stresses and affording a chance of planing the piece in its natural state.

Surface Tension

Another matter concerning distortion is the effect of removing the skin of a casting. This frees it from some amount of tension, and a warping process ensues. Many of the thinner specimens will develop a curve, and then when the other side is planed will flex back again. Hence attention must be paid to such possibilities, and clamping done with discretion, while it is often advisable to rough out and put castings aside for a while to "season." In due course changes will cease, whereupon finishing is safe for the most accurate results.

Holding Thin Pieces

If clamps cannot be set on top of the thinner castings and plates because of the tooling which has to be performed there, alternatives are: end or side pressure by clamps rigged up as in Fig. 2; end or side grip

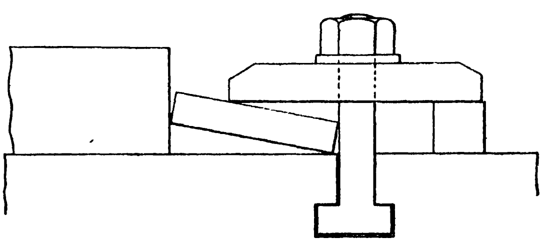


Fig. 2.—Method of obtaining pulling-down effect on work, if clamps must not be placed on the top

with one or more machine vices; pulling-down action with one or more magnetic chucks; thorough prevention of skidding by means of end stop plates is imperative.

Fixtures

When a quantity of similar parts must be held, unless they are very plain it is economical to provide a fixture which automatically locates and affords quick means of clamping. Setting may be by one or more flat pieces, by tapers, and sometimes by a hole in the work. In the last instance the fixtures have brackets through which a mandrel passes into the work, and setting comes from pads or screws touching it. A tool-setting gauge is a useful addition, consisting of a stud or studs or strips, enabling the operator to bring the tool down and set it finely by pulling a tissue paper through. If quantity required is sufficient, it pays to have a string of fixtures down the table. Special-purpose fixtures are employed in collaboration with a tool-controlling appliance, by means of which regular or irregular curves are planed.

Gang Planing

Great productive effort is obtainable by filling a long table with a single or double row of duplicate articles, saving time in setting and ensuring uniformity.

Rail Planing

Very strong and powerful machines deal with the strenuous duty or planing rails and switches, and the cross-rail is of limited height. Four tools may be taken by the four boxes.

Open-side Planing

In some shops castings of unusual width need to be planed, and for this service the open-side design is selected, a type which has grown much in favour. The cross-rail slides on a massive standard, and is powerfully constructed for heavy cutting. Castings of any dimensions may also be tooled on the vertical and horizontal machines, which have slides arranged to travel in either direction. Long objects of any awkward shape can also be put on the tables of a side planer, resembling a shaper, but having the saddle to run along the bed and carry two boxes on an arm reaching over the tables. Portable planing machines; possessing either horizontal or vertical stroke movement, attach to large castings or bolt to a T-slotted floor plate.

Tools

These bear resemblances to lathe tools, with the exception of some special styles, and, generally speaking, they have to be stiffer because of the overhang incurred when reaching down sides and under ledges. Principal shapes are (Fig. 3): round-nose straight, round-nose right- and left-hand, round-nose right- and left-hand bent tools, a straight-faced for finishing, some being with the

flat across the end, others on the flank, for side cutting, grooving, and T-slotting. The well-known goose-neck spring tool is often used for finishing, the slight elasticity preventing digging in. Form tools to plane angular or curved contours are much employed. Cemented-carbide tools are being used to an increasing extent. Tools of this type allow of higher cutting speeds and greater depth of feed.

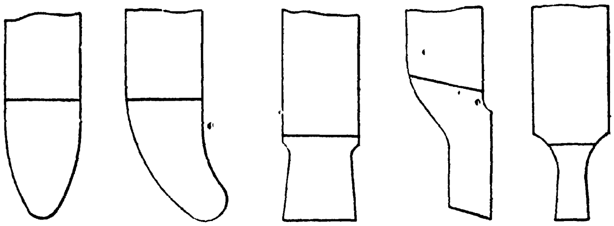


FIG. 3.—SOME OF THE MANY PLANER TOOLS
For straight and bent roughing, broad finishing, side finishing, and grooving.

Starting and Finishing

The shock at entering the metal may be lessened by filing a bevel on the end of the work, and for crystalline materials it may be well to do the same at the leaving end, to prevent breaking out there. Automatic control of electrically driven machines includes means of making a slow start if desired, the table speeding up after the tool has gone in a little distance, and likewise slowing down on leaving.

Roughing and Finishing

It is sometimes the practice to hold two tools for feeding across, the second one set lower, to finish the surface roughed out by the first. But generally it is better to undertake the operations separately, whereby the tremors and deflection produced by the roughing tool are not transmitted to affect the finishing one.

SHAPING PRACTICE

A considerable proportion of the pieces put on shaping machines are only of medium size, and are most conveniently gripped in a vice forming part of the equipment of every machine. Bolts and clamps are only wanted for large objects on top or side of the table, or on the base. The smaller machines run the ram in fixed guides at the top of the column, large ones in a slidable saddle.

Details of a Shaper

Fig. 4 explains the elements of a gear-driven machine. The ram (*B*) is reciprocated to and fro along its ways—in Fig. 4 by a rack and pinion with reverse gear operated by stops (*C*), to adjust the length of stroke. In another type of machine, the ram traverse is controlled by a crank of variable throw. Such machines are known as crank shapers.

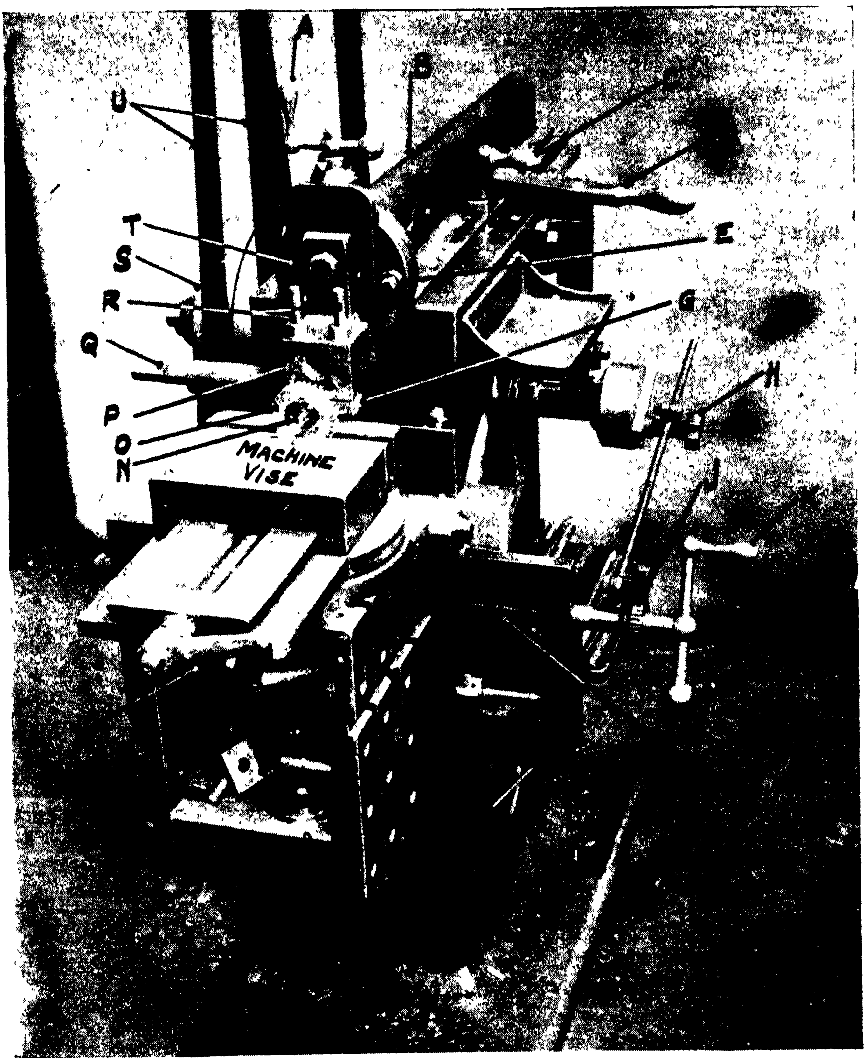


FIG. 4.—THE OPERATIVE DETAILS OF A SHAPING MACHINE

A, handle to tool-slide screw; *B*, ram; *C*, stroke trip-dogs; *D*, forward and return control lever; *E*, swivel clamping screws; *G*, toolholder clamping plate; *H*, feed control knob; *J*, feed ratchet; *K*, cross traverse handle; *L*, cross traverse screw; *M*, vice handle; *N*, keywaying tool and cutter holder; *O*, gear being keywayed; *P*, solid toolbox; *Q*, table-raising shaft; *R*, toolholder clamping screws; *S*, driving pulleys; *T*, tool slide; *U*, driving belts.

The actual cutting tool is essentially the same as a turning tool, even to the provision of a toolpost as holder (see Figs. 5 and 7), as is found on American-type lathes, except that no rocker is fitted, the tool always being clamped against a flat face. The toolpost for plain shaping is usually fitted on a pin hinge at its upper end, so that as it carries the tool backwards, it can lift up and avoid danger of chipping the cutting edge. On the return stroke, the toolbox, or "clapper box" (Fig. 7), automatically falls back into place, and the cut is taken by the rigid front of the tool slide.

Cutting Operations

It is hardly possible to make any comparison of a shaper with a miller, although they both undertake very similar kinds of work. The shaper will cut intricate forms but slowly, whereas such can be done rapidly on the miller, though involving expense for suitable cutters. A simple tool on the shaper can be manipulated to produce angles (Fig. 7); consequently, it is valued for general work and toolmaking. In addition, it is a simple matter to cut internal keyways and splines which a milling machine cannot do.

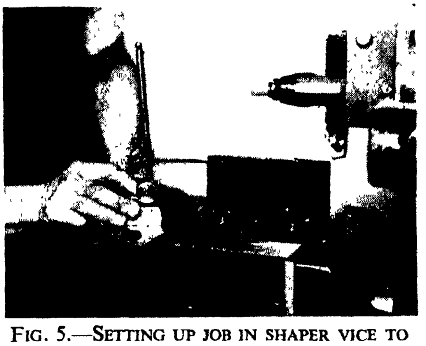


Fig. 5.—Setting up job in shaper vice to previously marked-out lines with surface gauge

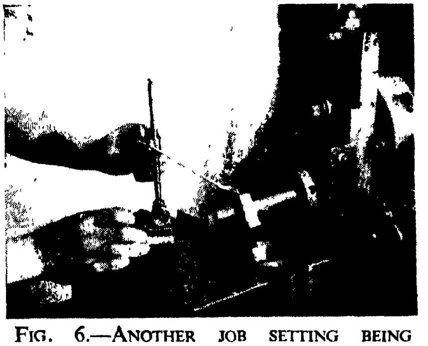


Fig. 6.—Another job setting being checked up with surface gauge on shaping machine

Tilting Tables

Increase of the capabilities of a machine is given by fitting a table which swivels, permitting work to be slewed to right or left. Or a tilting top may be had on the table, tipping towards the ram, for cutting taper surfaces.

Setting of Machine

It is sufficient for normal work if the tool is $\frac{1}{4}$ in. away from the work before starting to cut. At the end of the stroke, it is only strictly necessary that the tool goes over the edge, but $\frac{1}{4}$ in. clear over the length is advisable when possible. Tearing at the finishing edge is difficult to avoid if a big cut is being taken, but on particular work a piece of flat steel clamped against the edge and continuing the cut is all that is required.

Cutting Keyways

Keyways are cut with a cutter with square corners, smaller than the finished keyway. Lathe-boring toolholders make excellent holders for keywaying cutters. The holder may be held in the type of toolbox shown in Fig. 4. The cutter is fed up or down into the work. In the operation shown in Fig. 4 it was necessary to get a good grip of the gear at the bottom, therefore the feed will be upwards into the job. The cutter is then withdrawn, moved sideways, and again fed into the work until the desired width is obtained.

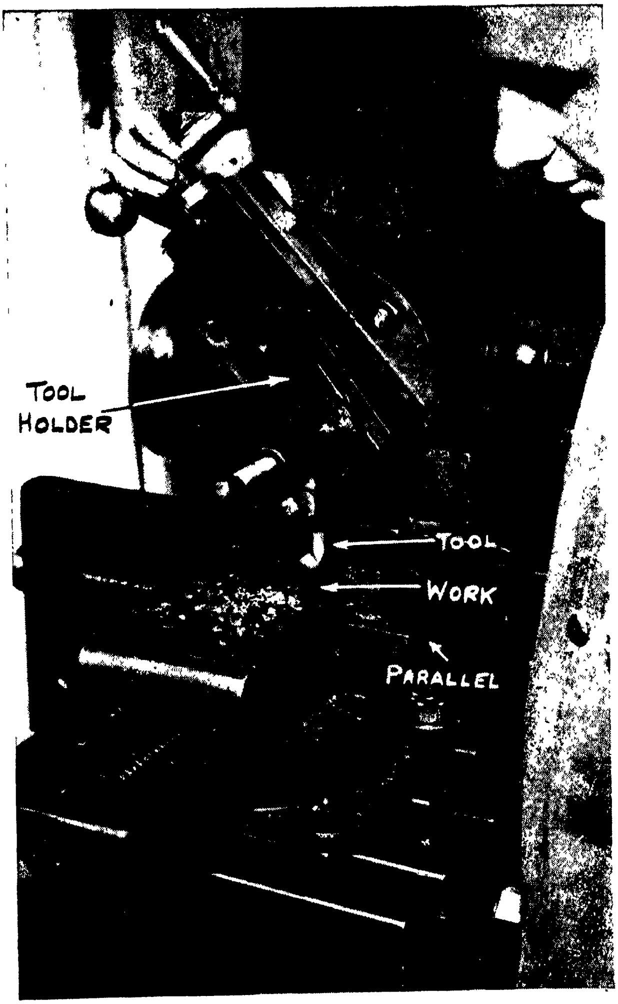


FIG. 7.—CUTTING OF A V-GROOVE ON A SHAPING MACHINE

To cut a keyway in a shaft on a shaping machine, first drill two flat-bottomed holes, one at each end of the proposed keyway. These provide starting and finishing clearance for the tool which is run between them and fed in to the required depth, after carefully adjusting the stops.

Machining Square Holes

Square holes are shaped with a square tool, smaller than the desired hole, and having on each side clearance front to back. A round hole is first drilled and the tool fixed so that the machine stroke traverses it through this hole. The cutter being accurately square if the table is moved left and right, and the

tool moved up and down, a square hole is the result. Rectangular slots or, indeed, any shape, can be cut in a similar manner.

Special Attachments

Railway and other shops make considerable use of shapers for heavy cutting, and attachments or fixtures chuck the repetition parts quickly. Axle-boxes, the shells or brasses, connecting-rod brasses, some kinds of shoes and wedges may be mentioned.

Grinding Attachment

For toolmaking purposes in particular a portable electric grinder affords facility for finishing dies, gauges, and other items, manipulation being effected by the usual table and toolbox motions.

Large Machines

With a long bed carrying two traversing heads, large castings and forgings can be shaped on any parts, with or without further setting according to circumstances. Three tables are convenient for rapid handling, because objects may be set and clamped on a free one while shaping is going on at the other two, and a head may be run along, when free, by rapid power traverse thereto.

E. M.

BROACHING MACHINES AND PRACTICE

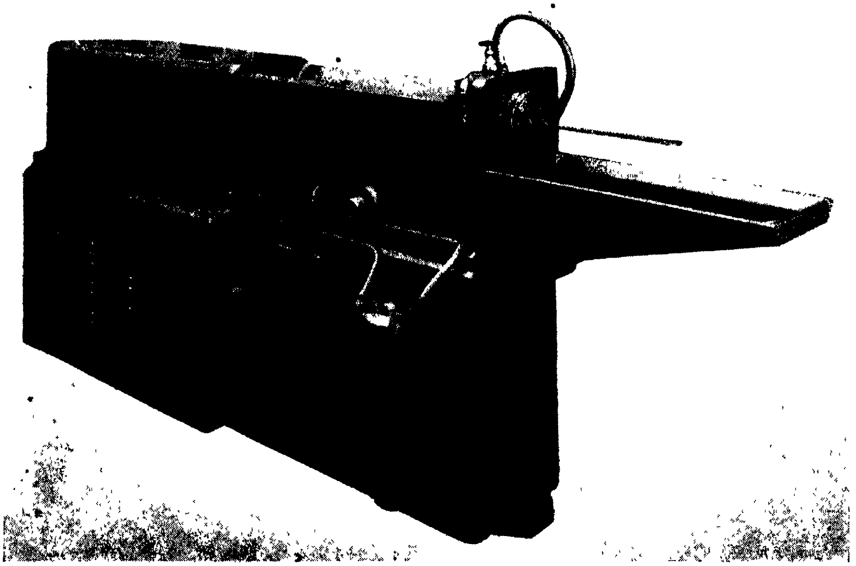
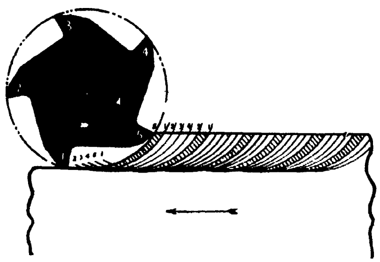


FIG. 1.—THE LAPOINTE 5-H.P. HORIZONTAL HYDRAULIC BROACHING MACHINE, WHICH HAS A PULLING FORCE OF 5,500 LB. (*Lapointe Machine Tool Co., Ltd.*)

BROACHING is a machine-shop operation for the removal of metal over a continuous contour by means of a cutting tool, which is either pushed or pulled over a surface or through a hole. The design of the tool is well described by the word "broach," derived from the Latin *brocca* or *broccus* and meaning a projection of teeth.

The broach or cutting tool is provided with a number of teeth shaped to the same contours as those to be produced on the work, each projecting slightly farther than the preceding tooth. As the tool moves over the surface of the work the metal is progressively removed, until the last few teeth provide the final profile and dimensions. Fig. 2 illustrates the principle of broaching contrasted to that of milling.



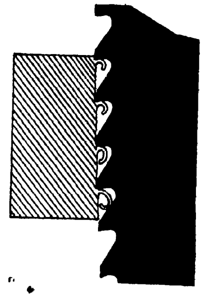


FIG. 2. — TWO EXAMPLES SHOWING THE CONTRAST BETWEEN MILLING AND BROACHING OPERATIONS

Advantages of Broaching

Broaching is an operation of considerable importance, because it makes possible the machining of many types of surface which, because of their difficult profiles, often cannot be machined by ordinary methods. The faces to be broached must have all their elements parallel to the axis of the broach holder, but by suitable setting of the teeth several faces can be machined at one stroke of the ram.

It is also an exceptionally quick operation; machining is completed by a single pass of the tool over or through the work, and the tool passes over the work surface at a rate many times greater than is possible with milling, the process most generally used for the same type of work. The time required for loading and unloading fixtures is less, because normally it is only necessary to support and hold the workpiece against the forces of the cut, and preloading is in most cases unnecessary.

Each tooth removes only a very small amount of metal, and this gradual cutting results in an exceptionally fine finish, and eliminates the need for grinding or similar finishing operations. Since each tooth is designed to remove a certain fixed thickness of chip, close tolerances are obtained.

A high output is possible before resharpening is necessary, because each tooth of a broaching tool only strikes the work once, and actual cutting speeds are comparatively low. Also, the abrasive action which every tooth experiences during orthodox "upcutting" in milling is eliminated.

These advantages show that broaching is an efficient and accurate method of meeting the demands of high-production operations, provided that certain essential conditions are satisfied.

Conditions Necessary for Broaching

The most important condition is that production quantities should be high. If one machine is used for more than one operation or component, necessitating tooling changes, quantities in each run should be as large as possible. Stock removal should be tied to a reasonably constant figure, or broach inserts will be unnecessarily expensive, output will be reduced, and in certain instances it may be that a larger machine than is absolutely necessary will have to be installed.

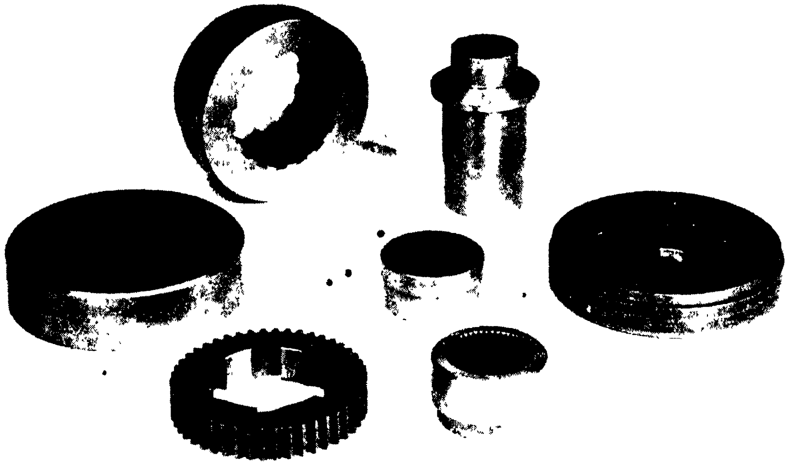


FIG. 3.—EXAMPLES OF INTERNAL BROACHING

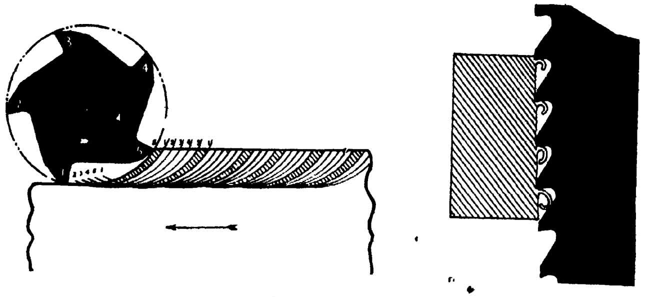
The component to be broached must be capable of being located and clamped easily and quickly, and the faces to be broached must have all their elements parallel with the axis of the broach holder. It is also essential that there should be no obstructions in the path of the faces.

The final condition is that the component must be inherently strong and capable of withstanding the stresses set up by broaching. The forces involved operate in three definite directions, one along the path of the broach, a second at right angles to this path tending to separate the work and the tool, and the third introduced by whatever shear angle is on the tool.

Typical Examples

All these points can best be illustrated by a few examples. For instance, illustrated in Fig. 3 are several components incorporating internal splines, keyways, a square, and a hole of special profile. Apart from broaching, these special internal contours can only be produced by slotting or on a gear-cutting machine of the Fellows type. At the very best, machining would occupy several minutes, whereas the parts can be broached in a matter of seconds by a single pass of the tool.

The diagram in Fig. 4 (*a*) represents the outline of a forged-steel rifle bolt, the thick line denoting an arc and two straight sides which must be machined to a high degree of accuracy. The alternative to broaching would consist of form milling or form grinding, and the work would have to be set up either two or three times in order to cover the required surfaces. Even with special holding fixtures this would occupy five minutes or more, and resetting the work several times would introduce chances of error. In contrast, three bolts are broached



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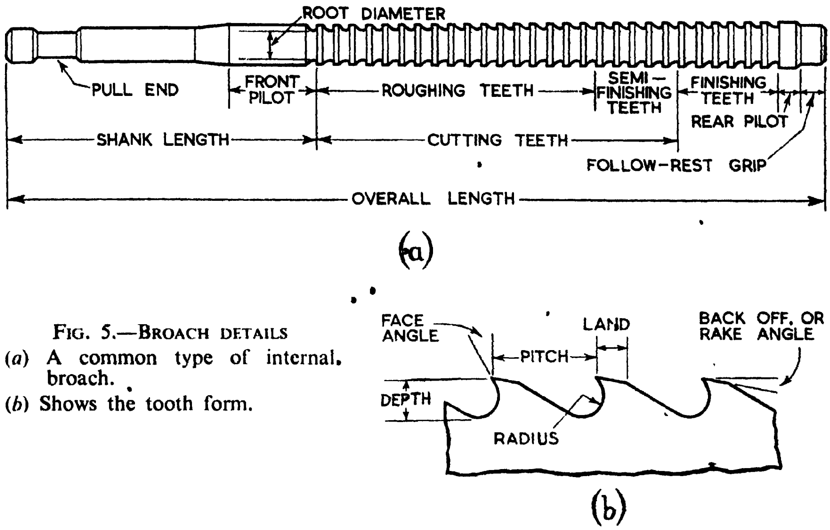


FIG. 5.—BROACH DETAILS
(*a*) A common type of internal broach.
(*b*) Shows the tooth form.

edge of the tooth, the notches being staggered so that the material left by one tooth is removed by the next.

For internal work, the teeth increase in diameter from the first roughing tooth to the first finishing tooth, but the increase need not necessarily be uniform. In actual practice, it is greater for the roughing teeth than for the intermediate semi-finishing teeth, so that the latter remove less metal than the former. Normally, all the finishing teeth are the same diameter, thus ensuring very accurate sizing and providing a good quality of surface finish.

It is always necessary to provide a hole into which the broach can enter. This may be drilled, turned in a lathe, etc., or, in some cases, merely consist of a cast hole. From Fig. 5 (*a*) it will be seen that near the front end of the broach is a parallel portion known as the "pilot": this enters the hole first, and serves to centralise the tool.

At the front end of the broach is the portion which is gripped in the pulling head of the machine. Each manufacturer has his own particular design, some of which are seen in Fig. 7; but the main feature of all types is that they must allow the broach to be gripped quickly and firmly.

Spiral Broaching

A slightly different type of tool is used for producing spiral splines and keyways. In this case, flutes of the required helix are provided along the length of the broach. Using this special tool, spiral broaching can be achieved in two different ways. With one, the work is fixed and the broach held in a special head which rotates slowly during the cutting stroke. Alternatively, the work is held in such a manner that it is free to rotate; thus, as the broach is pulled

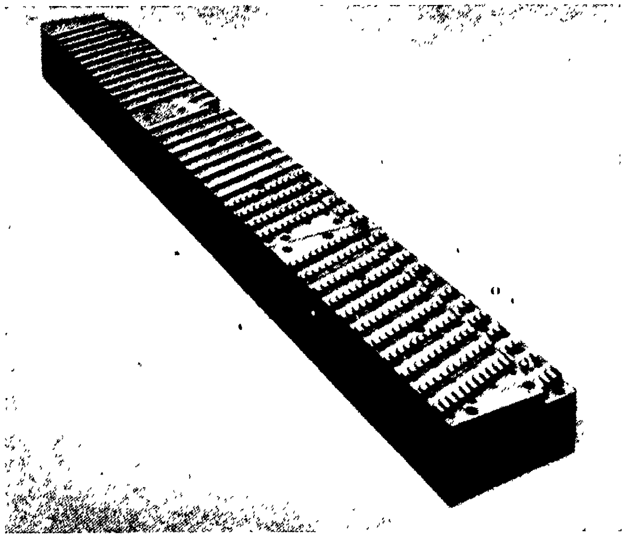


FIG. 6.—A SIMPLE SURFACE BROACH

through, the work is rotated by the tool itself without the need for gearing or any other device. Naturally, the broach must be specially designed for the purpose.

Surface Broaches

For machining flat external surfaces, a broach, such as seen in Fig. 6, is employed. As with internal types, each tooth projects slightly farther than its neighbour, until the finishing section is reached when, generally, the height of the last few teeth is uniform. The width of the tool is the same as the width of the work, so that the surface is finished in a single pass. To facilitate manufacture and reduce costs, the larger broaches are generally made in short sections, which are secured to the machine ram to give the equivalent to a single long broach. Although, for simplicity, a slab broach is shown in Fig. 6, the teeth may be shaped to any desired profile.

Cutting Fluids

The use of a lubricant or cutting fluid is essential for the production of good-quality work, and to ensure maximum tool life. The type of fluid employed is to a large extent governed by the class of material being machined and by the amount of metal to be removed. In general, heavy metal removal requires a fluid which lubricates rather than cools, whilst if only small amounts of metal are to be removed, cooling becomes more important than lubrication, i.e. a lighter fluid is desirable. Normally, internal broaching requires a heavier fluid

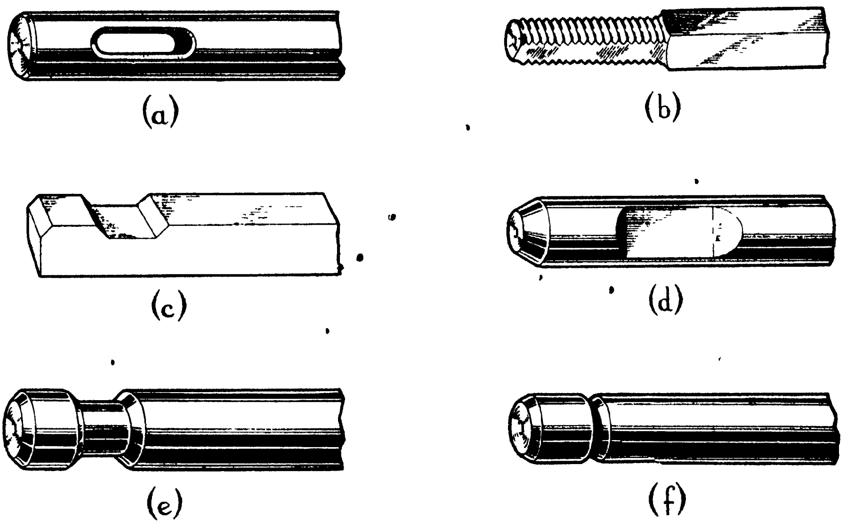


FIG. 7.—TYPICAL EXAMPLES OF BROACH-PULLING SHANKS

than surface broaching. If a high-class finish is not required, cast iron may be broached dry, but the use of a light fluid such as paraffin is desirable when a good-quality surface is essential.

Work Fixtures

Broaching is a very speedy operation; one pass of the tool and the job is finished. Consequently, it usually takes longer to load the machine, i.e. secure the work, than to perform the actual machining operation. For this reason, considerable importance attaches to the use of quick-action work-holding fixtures which reduce loading and unloading times to a minimum. In every case, these are designed specially for the work in hand, and are rarely suitable for any other job.

The ingenious nature of some fixtures is well illustrated by the example in Fig. 8, which has been developed for holding connecting-rod parts when broaching with a double-ram horizontal machine. It incorporates quick-action locking devices which reduce loading times, and the tables can be swung clear to facilitate insertion of the workpieces.

For long runs of work, special fixtures and feeding arrangements are generally employed. For example, it is quite usual for these to include magazine loading, automatic transfer from the magazine to the fixture, and automatic ejection of the finished part on to a conveyor or into a bin. The use of multi-fixtures and tools enables several components to be broached simultaneously.

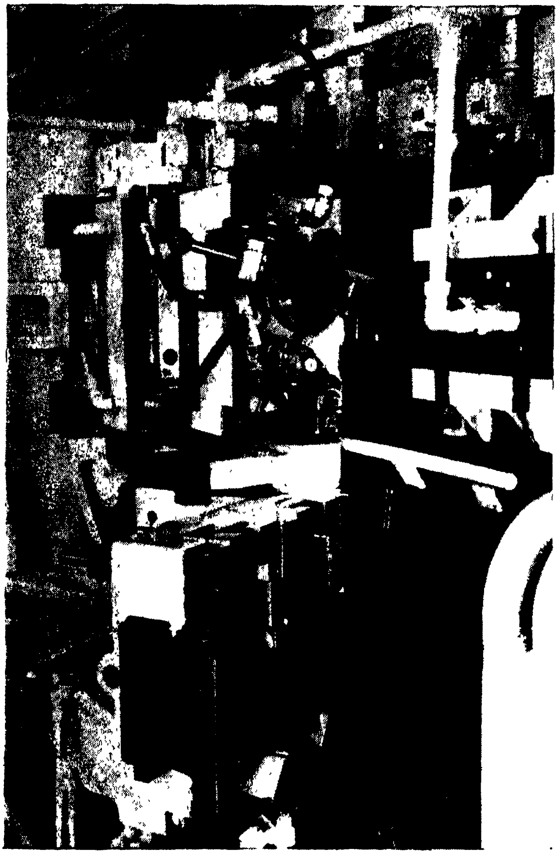


FIG. 8.—A FIXTURE DEVELOPED FOR HOLDING CONNECTING RODS WHEN SURFACE BROACHING ON A HIGH-PRODUCTION HORIZONTAL MACHINE

TYPES OF MACHINES

Broaching machines are built in two main types, i.e. horizontal and vertical, both of which can be subdivided into further groups: these machines may have one or more rams according to production requirements.

Horizontal Machines

Practically all horizontal machines are of the pull type, i.e. the broach is pulled through or over the work. The early models of this machine comprised a suitable body with a screw which passes through a long nut on which are mounted the three belt pulleys. By means of open and crossed belts the nut can be caused to rotate in either direction, thus drawing the screw either to the right or left. At the free end, the screw incorporates a suitable holder for gripping the end of the broach.

At the opposite end of the pulleys is a sturdy faceplate or platen with a hole arranged on the same centre line as the screw. Thus, when broaching, it is only necessary to pass the end of the broach through the hole in the workpiece, through the hole in the faceplate, and grip it in the quick-action holder. Appropriate movement of the belt then causes the nut to rotate, drawing the screw and broach through the workpiece. It will be observed that the broach is subjected to a straight pull and does not rotate, and thus it is not necessary to secure the workpiece, which is held firmly against the faceplate by the broaching pressure. By means of suitably placed dogs, the belt is automatically shifted from one pulley to the other at the end of the broaching stroke, thus returning the screw in readiness for the next component.

On modern machines (Fig. 1) the screw is replaced by an hydraulically operated ram which draws the broach smoothly through the work. The length of stroke is automatically controlled, and at the end of the broaching stroke the ram is returned at a fast speed in readiness for the next operation.

The horizontal model is the most universal type of broaching machine, since it is capable of performing a very wide variety of work. Although it is used chiefly for internal broaching, such as holes, keyways, and splines, it can also be used for broaching external surfaces if equipped with the necessary fixtures. For such work, the broach is permanently secured to the drawhead.

In contrast to the general-purpose type of machine seen in Fig. 1, some very interesting special-purpose versions have been developed. For instance, a machine developed for producing the rifling in the bores of gun barrels is provided with either 5, 6 or 7 broaches, which are all pulled simultaneously through a similar number of barrels held in a special indexing fixture midway along the machine. It will be remembered that the rifling of gun barrels follows a spiral path, and to achieve this the barrels are revolved during broaching by means of a train of gears.

In operation, the broaches are fed through the barrels, gripped in their holders, and the latter then caused to move to the right. As soon as the broaching movement commences, the barrels rotate slowly to produce the necessary helix. Each broach is slightly larger than its neighbour, so that the last broach finishes the barrel to the required dimensions. During broaching, coolant is fed under pressure through the barrels. With this equipment the average production is 60 barrels per hour, an output which is impossible by any other means. This particular set-up provides an interesting example of the possibilities of broaching for high-production purposes.

Vertical Types

Vertical machines may be divided into two main groups, i.e. the "push-down" type, in which the broach is pushed through the work, and the "pull-down" type, where the broach is pulled through the work, the latter being further subdivided into pull-up and pull-down models according to the direction of broach movement. The standard vertical machine is a high-production machine which may operate one or more broaches simultaneously. It is often equipped with automatic broach-handling mechanism which makes it unnecessary for the operator to handle the broaches manually even on internal work, this being an important feature when the tools are large and heavy. As a rule, external broaching can be performed more easily on the vertical type than on horizontal machines.

Pull-up Type

The pull-up type was the first to be developed, and is used generally for the internal broaching of round holes, splines, irregular holes, and gear teeth, particularly when it is not important for the location of the broached surface to be accurately related to some external part of the work surface. When broaching,

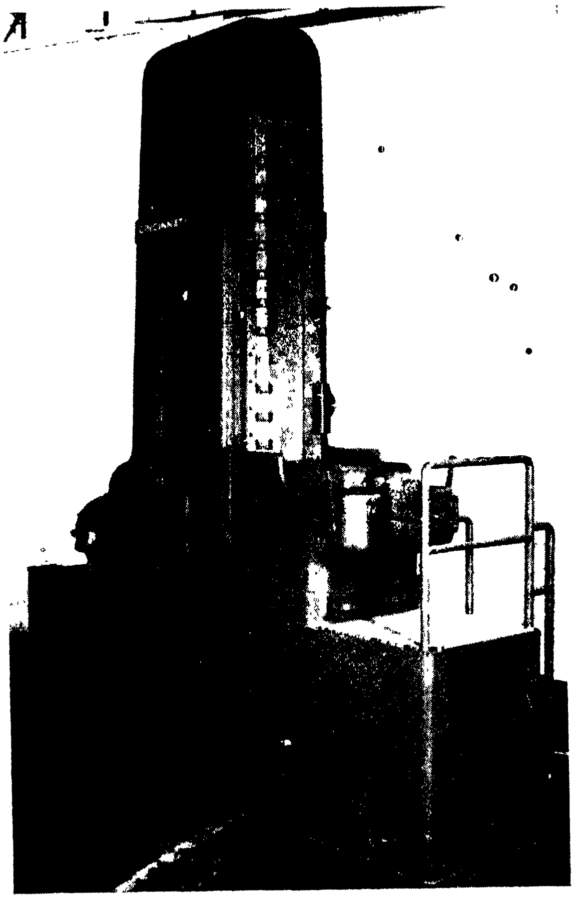


FIG. 9.—A VERTICAL PULL-DOWN MACHINE
(*Cincinnati Milling Machines, Ltd.*)

the work is placed against the lower face of the work table, over the front or pilot end of the broach. Then, with the work held against the underside of the table, the broach is pulled upwards through it. The work is then removed and the broach returned to its original position under the table. This type of machine is only made with a single ram.

Pull-down Type

The pull-down machine (Fig. 9) was developed from the previous type and possesses certain advantages. In particular, the work is broached on top of the table, and thus can be more easily observed and handled. Like the previous type, this machine is used largely for high-production internal work, but has the added advantage that it is possible to locate the broached hole accurately in relation to the external contours. This is done by means of a special fixture on the work table and a locating tang on the broach puller. With this machine, the broach is suspended above the work table. When broaching commences, the tool is lowered until the pilot end passes through the hole in the component, when it is automatically gripped by the puller head and disconnected from the holder at the top. It is then pulled downwards through the work, the component removed, and the broach automatically fed upwards until it engages the handling mechanism, which returns it to the original position above the work table. These machines are available with one or more rams.

With a simpler type of pull-down machine a certain amount of manual

handling is necessary, but, because of the small size of the broach, this does not cause undue fatigue. The component is laid over a hole in the table and the pilot end of the broach dropped through. Fingers then automatically engage the end of the broach and pull it through the work, releasing it at the end of the stroke so that it may be lifted up by hand and dropped through the next component. This extremely simple machine is available with a pulling capacity up to 10 tons, and is capable of broaching parts at the rate of 250 per hour. By means of a foot control, the operator is left with both hands free to handle the work.

Push-type

Push-type machines are available in two styles, one for the use of the normal type of internal push broaches and the other designed primarily for surface broaching. The former may be equipped with a device to keep the tool from falling into the base of the machine at the completion of the stroke and to return it as the ram moves upwards again. With the aid of a suitable fixture and tool support, this machine may easily be adapted for surface broaching.

Because of the manner in which the pressure is applied, long broaches cannot be used, and thus this type of machine is generally reserved for work from which only a little metal is to be removed, i.e. where short broaches can be applied. One typical use is for sizing holes in order to correct distortion arising from heat treatment. They are also useful for short runs of work where the cost of a long tool would not be justified. When not required for broaching, these machines are often used as an ordinary press for straightening purposes.

Surface Broaching

Surface broaching machines may be divided into three groups, i.e. horizontal, vertical, and special-purpose, the choice of type depending upon the class of work to be broached and the size of output required.

Vertical Types

Vertical surface broaching machines cut on their downward stroke, and incorporate one or more rams fitted with holders which carry the broaching tools, the latter being held in position by screws, clamping blocks, or other means enabling them to be adjusted or changed without difficulty. It is quite common practice to use twin-ram machines arranged so that the tools on one ram are cutting whilst the other ram is returning to the top of its stroke. Thus, with the aid of quick-loading devices, it is possible to load one component whilst the other is being broached. This arrangement gives practically continuous production and results in a very high output.

The work is held in one or more fixtures fastened to a horizontal table or platen that recedes from the cutting position at the completion of the downward stroke of the ram in order to allow the operator to safely remove the work and reload while the ram is returning to the top of its stroke. The table then returns to the cutting position in time for the next downward stroke. These machines

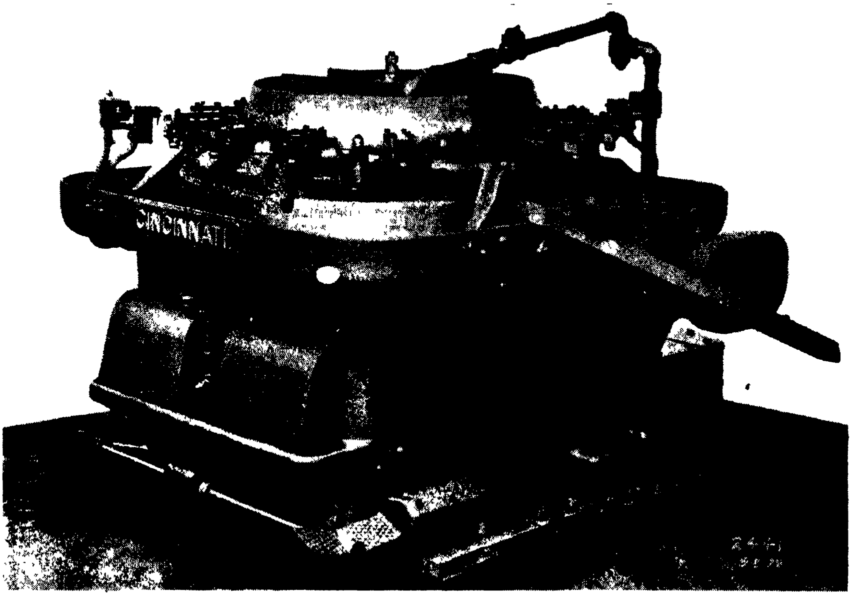


FIG. 10.—SPECIAL-PURPOSE ROTARY BROACHING MACHINE
This machine has an output of 3,800 pieces per hour. The tools are mounted in the centre, and the work-table indexes around them. (*Cincinnati Milling Machines, Ltd.*)

are hydraulically operated, and the table movement is usually interlocked with the ram movement in order to prevent accidents. Often, the work clamping fixture is also hydraulically operated and interlocked with the ram movement.

Continuous Machines

Where a very high output is required, special continuous broaching machines are available. In appearance, they are very similar to the ordinary vertical machine, the main difference lying in the design of the workholding fixture. For instance, one machine employs a continuous chain conveyor which carries the components past several broaching stations, the broaches merely moving up and down continuously. Another type is the rotary machine (Fig. 10), in which the broaches are mounted on a central column and the work moved past the broaches on a rotary table. Often, each fixture is provided with an automatic clamp, the operator merely loading the component: after completion of broaching, the parts are then automatically discharged.

J. A. O.

FORGING AND SMITHING OF STEEL.

THE working of hot metals is one of the oldest of the arts and crafts, yet one which, even in modern times, has had astonishingly little scientific attention. Practices, many of them essentially sound, persist by tradition rather than reason; and, on the other hand, much skill and knowledge which was obviously available in early historical days has been lost because there were no written records. To-day we cannot but marvel at the wonderful workmanship which produced, with so little scientific knowledge, the swords of Damascus and Toledo, the plate and chain mail of mediæval times, and the ornamental ironwork of a later period.

It is not proposed to trace here the development of forging plant from the hand hammer of the ancient smith, through the trip hammer actuated by water wheel, to the steam hammer invented by Nasmyth, the electrically driven pneumatic power hammer, and the hydraulic forging press. Modern plant will be described later, and it is sufficient to say that the machines now available are in every way capable of meeting the requirements of the industry.

To-day, much is known about the chemical composition, micro-structure, physical properties and heat-treatment of steel and its alloys, but not a great deal about the internal mechanism of deformation during hot forging. The researches made by Harold F. Massey in 1920 provide a reasoned explanation of certain phenomena well known to practical smiths, and throw some light on the process of deformation either by hammering or by squeezing.

Special Characteristics of Steel

The first point to be noted is the resistance to flow caused by the frictional grip of the palletts (or tools). If a cylindrical piece of hot metal is placed on end and given one or a series of blows or squeezes, the height is reduced and the diameter increased; but the result is not, as might be expected, a shorter, fatter cylinder. The sideways flow of the metal at the top and bottom where it is in contact with the palletts has been impeded, and as a result the

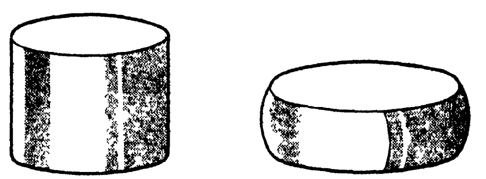


FIG. 1.—FORM TAKEN BY METAL OWING TO RESISTANCE TO FLOW CAUSED BY THE FRICTIONAL GRIP OF THE PALLETTS

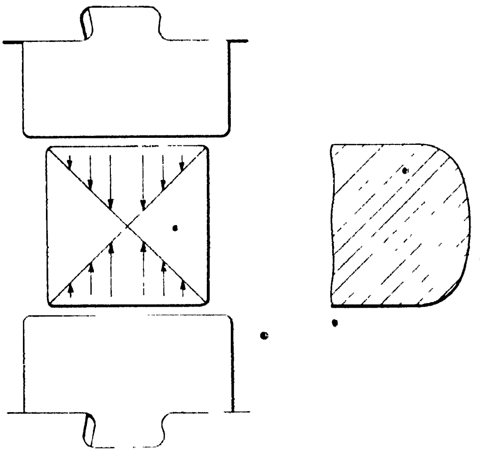


FIG. 2.—THE TOP AND BOTTOM PYRAMIDS MEET, OR OVERLAP, MAXIMUM SIDEWAYS FLOW OF METAL BEING IN THE CENTRE

metal takes on a cheese-shaped form with rounded sides, as shown in Fig. 1. In other words, the flow of metal is greater near the centre of the piece. Further experiments showed the reason for this, namely, that the area of the forging in contact with the pallett is, in effect, the base of a pyramid, the impedance to flow falling off as the distance from the pallett increases. If the height of the material is less than the width of the palletts in contact, the top and bottom pyramids meet as in Fig. 2, or overlap, and the maximum sideways flow of the metal is in the middle. If the height of the material is greater than the width of the palletts in contact, the two pyramids do not meet and the greatest sideways flow of metal is not at the centre but at the apices of the pyramids. This is exemplified in a circular forging as shown by Fig. 3. That practical smiths have been aware of the result of this phenomenon, if not of its cause, is shown by the fact that in drawing down a piece of steel a good smith always forges it square until approximately the right size is attained and only then proceeds to round it off or swage it into the circular shape required.

It must be observed that to the surface friction referred to above must be added the surface cooling which results from contact of the hot metal with the cold palletts. This cooling is, of course, greater with a press than with a hammer, but the shape of the pyramid is not affected, and experiments showed clearly that while there is little difference between the effect of a blow and a squeeze, the hammer does, if anything, forge to the centre of the metal better than the press.

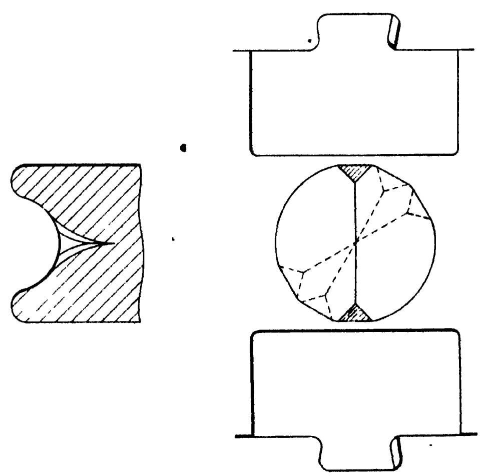


FIG. 3.—CIRCULAR FORGING

Note that the sideways flow of metal is at the apices of the pyramids.

FORGING OF NON-FERROUS METALS AND LIGHT ALLOYS.—It is not proposed to deal here with the forging, either hot or cold, of non-ferrous metals, although such work is done regularly to a small extent—the cold hammering of copper sheets, for instance, to form vats, and the preforming of light alloys before drop-forging in dies. The hot working of light alloys is, however, specialised work which would demand a treatise on its own; and the remarks which follow deal primarily with the forging of steel.

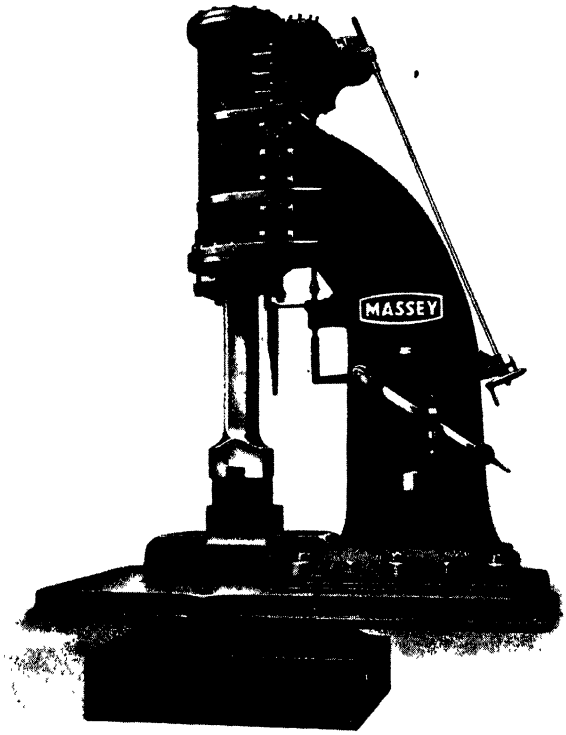


FIG. 4.—20-CWT. STEAM HAMMER, RIGBY TYPE, WITH SLIDES
(*B. & S. Massey, Ltd.*)

The Manufacturing Process

This may conveniently be divided into two principal functional classes—the manufacture of the steel itself and the making from the steel of particular articles.

COGGING.—Forging, however, in one form or another enters largely into the manufacturing process. The cast ingot, either reheated from cold, or at the correct moment in its cooling process, is taken to a hammer or press, the waste

ends are removed, and the sound portion is forged down and drawn out to form a bloom, the structure of the metal being greatly improved in the process. This is known technically as "cogging." The bloom may be sold as such, or a further reduction in section may be effected, either by hammering—at this stage known as "tilting"—or by rolling. The latter, though a method of working hot steel, is not strictly forging and will not be dealt with here. Since the cogging and tilting processes are straightforward and continuous drawing

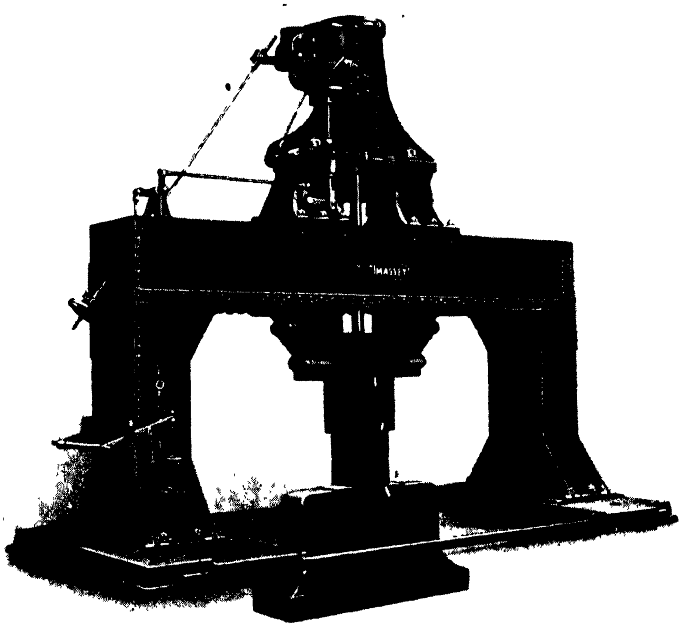


FIG. 5.—THREE-TON STEAM HAMMER, GIRDER FORM, WITH SLIDES
(*B. & S. Massey, Ltd.*)

out, they are more exacting than ordinary forging, which is necessarily intermittent, with pauses for adjusting tools. The hammers used for cogging are therefore usually provided with heavier anvil blocks, and the tilting hammers are of special design running at higher speeds, with shorter strokes, than normal forging hammers.

Very large cogging hammers have been built—records exist of one with a falling weight of 108 tons in Italy, and one of 100 tons in Pittsburg; but they were very expensive to make, maintain, and use, and caused so much vibration that they were soon put out of commission. The largest ingots are now invariably forged under hydraulic presses, and hammers of much above 10 or 15 tons falling weight are rare. As a comparison it may be said that a 1,000-ton press is approximately the equivalent of an 8-ton hammer.

FORGING IN CLOSED DIES.—The forging of metal in closed dies is dealt with in a separate section, and the term "forging" is here used to denote the process of shaping the metal between plain palletts, with, of course, the aid of loose tools such as cutters, swages, etc., where required. The hydraulic forging press is again used for the largest forgings which are made direct from the ingot. Although the press would appear to be a clumsy tool, quite complicated forgings are made, such as, for instance, rudders and stern frames, in addition to more straightforward objects such as large shafts.

Steam Hammers

The first real power hammer was, of course, Nasmyth's steam hammer, suggested by him as a means of making a large marine crankshaft too big for any of the existing tilt hammers. These tilt or beam hammers were used even in the Middle Ages, and consisted of a hammer head mounted on a strong shaft, lifted by a cam and falling under the action of gravity. Nasmyth's hammer was "double-acting," i.e. the tup was thrown down by the pressure of steam above the piston as well as lifted by pressure beneath the piston. In essentials his design has remained unaltered, although, naturally, frames have been strengthened and refinements in guiding and control have been introduced. The very large hammers referred to above were pressure lifted only.

Modern steam hammers may be divided into four standard classes—arch form with slides, overhanging form with slides, the Rigby type without slides (Fig. 4), and the tilting hammers. The last named are merely a variation of the standard arch-form hammers, but with shorter strokes and a quick-running, automatic valve gear. They are also provided with anvil blocks weighing twelve or more times the weight of the falling parts. It may be interpolated here that the nominal size of a hammer indicates the actual weight of the falling parts, and does not take into account the pressure above the piston which, of course, accelerates the fall and increases the blow energy. Although this nomenclature falls short of telling the whole story, no other more scientific method has been devised.

In normal forging hammers the anvil block nominal size ratio is usually 10:1.

Hammers of the overhanging form are used for small smithing work and tool smithing, and normally have an automatic, or self-acting, valve gear.

Hammers of the Rigby type, first designed by a Scottish engineer of that name, dispense with slides, the large-diameter piston rod being guided by a deep stuffing box at the bottom of the cylinder. There is, therefore, more room round the palletts, and better visibility, and hammers of this type are popular in shipyards and other forges where awkwardly shaped forgings have to be dealt with. The valve gear is normally hand operated, a separate movement of the lever being required for each blow. These hammers are made up to about 40-cwt. size.

For larger hammers the original arch form is adopted, although a variation

of this design, also useful where large forgings have to be made, is shown by Fig. 5, which illustrates a 10-ton girder-form hammer. In the arch-form hammers the standards, now usually of box form, are normally of cast iron, although cast steel is preferable for exacting conditions. Under such circumstances the anvil block should also be of cast steel, or at any rate provided with a separate steel top into which the actual pallett is keyed. The valve is operated by hand.

Special steam hammers are made for particular work (see Fig. 6).

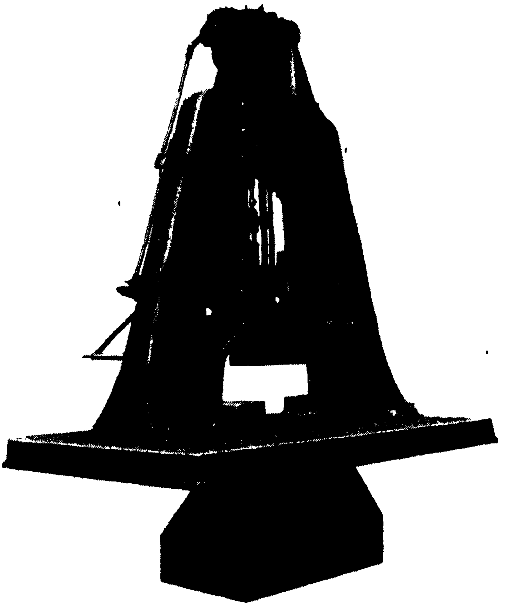


FIG. 6.—THREE-TON STEAM HAMMER, "A" FORM, FOR FORGING RAILWAY AXLES
(*B. & S. Massey, Ltd.*)

Valve Gear

The simplest type of valve gear for all steam hammers is that in which the tup near the upper limit of its stroke strikes a "tripper," which reverses the valve position and throws the tup down again. The driving of such a hammer requires skill and practice, and can be dangerous to the forgeman. Refinements are available, one of which, by imparting a rotary movement to the valve as the tup rises and falls, cuts off the admission of steam and uses its expansive action thereafter. This "expansion valve gear" is absolutely safe, and, of course, more economical.

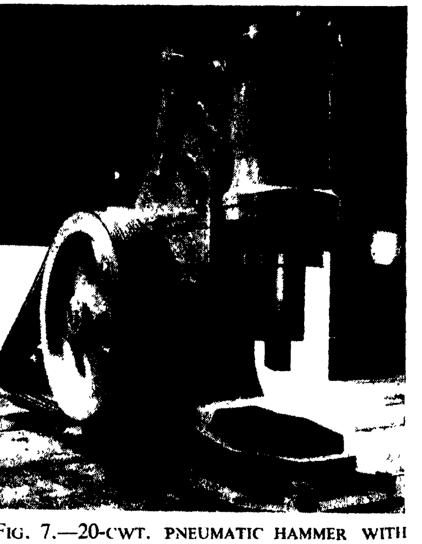


FIG. 7.—20-CWT. PNEUMATIC HAMMER WITH V-BELT DRIVE
(*Eumuco (England), Ltd.*)

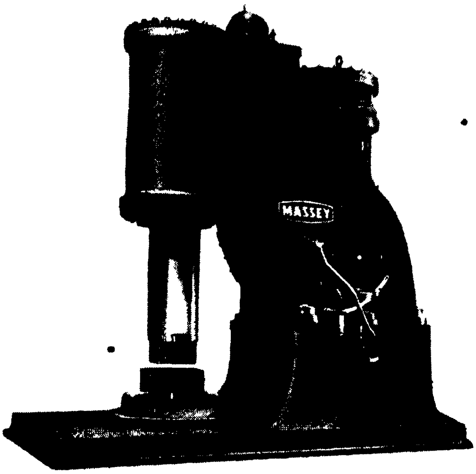


FIG. 8. — ELECTRICALLY DRIVEN 40-CWT. "CLEAR SPACE" PNEUMATIC HAMMER, WITHOUT SLIDES

(*B. & S. Massey, Ltd.*)

Pneumatic Power Hammers

As electricity became more readily available and steam more expensive, an alternative to the steam hammer was sought, and the electrically driven pneumatic power hammer was introduced. The cleanliness, economy, convenience, and fine control of the modern pneumatic hammer have led to its adoption in preference to a steam hammer for a majority of forging and smithing operations. It is limited in size to a maximum of about 40 cwt., and larger hammers, where steam is not available, have to be driven instead by compressed air supplied by a separate compressor.

The pneumatic hammer incorporates its own compressor, the air being mainly used as a spring between the pump and the hammer piston. The best modern hammers will, however, strike definite, controllable, single blows in addition to the automatic range. Fig. 7 shows a hammer with slides, Fig. 8 a "clear space" hammer without slides, and Fig. 9 a section of this latter hammer. All the working parts are enclosed and lubrication is entirely automatic.

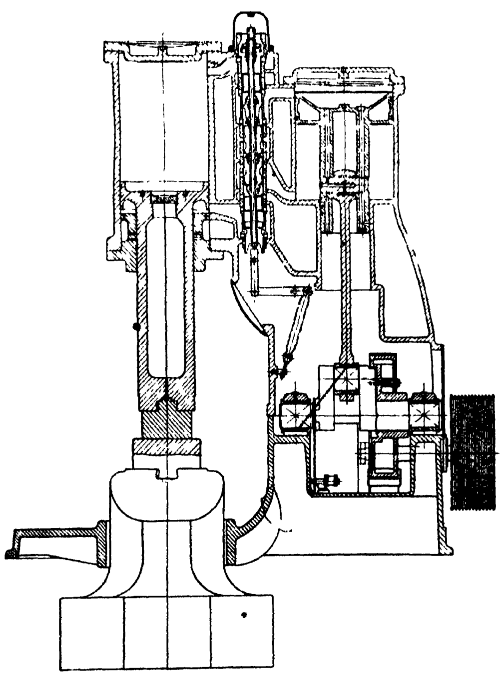


FIG. 9.—SECTION THROUGH A "CLEAR SPACE" HAMMER

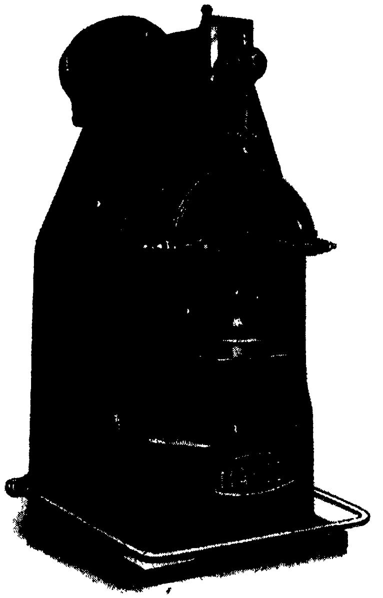


FIG. 10.—HALF-CWT. SPRING HAMMER (*B. & S. Massey, Ltd.*)

Because they use the air at the temperature to which it is raised by compression, because there are no clearance losses, and because power is used only as actually required for the blows struck, pneumatic hammers are, except under very exceptional circumstances, much more economical than steam or compressed-air hammers. In Britain, with coal at, say, 52*s.* 6*d.* per ton and electricity at 1*d.* per unit (kWh.), a steam hammer of 10-cwt. size will cost anything from 18*d.* to 24*d.* per hour according to the type of hammer and the steam raising conditions; the same hammer driven by compressed air would cost about 9*d.*–13*d.* per hour, and a pneumatic hammer only 4*d.*–7*d.* per hour.

As some guide to the choice of a hammer for ordinary smithy work, it may be said that a 5-cwt. hammer will deal efficiently with forgings to be made from mild-steel bars of from 4 in. to 8 in., a 10-cwt. from bars of 6 in. to 12 in., and a 20-cwt. from bars of 9 in. to 17 in. It is, however, wise to choose a hammer reasonably on top of its work.

Spring and Helve Hammers

For light, straightforward drawing out, two further types of hammer are available—spring hammers and helve hammers. The latter are much used in America for drawing out and swaging work in connection with drop forgings, either for preparing before stamping, or for finishing after stamping, one part of the object in dies. Spring hammers are used for plating table-knife blades, drawing out the prongs of garden and other forks, and similar work. Fig. 10 shows a hammer of ½-cwt. capacity. Both helve and spring hammers run at a fairly high speed, but being controlled by the medium of a clutch, are subject to the disadvantage that they slow down on light blows, when the speed should really be at its greatest.

Palletts

Although most forging work proper is done with plain palletts, special palletts can with advantage be used on occasion. If much swaging work of a fixed diameter has to be carried out, the swaging impressions can be cut in the

pallett faces. The palletts used for "tagging" tubes prior to drawing are shown by Fig. 11, and specially grooved tools, either fixed or loose, are employed in forging files and similar work. Even where plain palletts are used, separate loose tools are employed to help shape the work to the required form—for instance, round tools for necking down, V-tools for forming shoulders, swages for rounding up, and cutters for removing surplus material from the end of the forging or for separating the forging from the bar. A selection of such tools is shown in Fig. 12. It is also customary, when forging material down to a fixed size, to use a stopper between the palletts to prevent the forging being made under size.

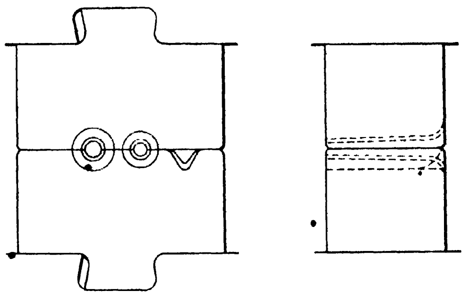


FIG. 11.—PALLETTS FOR TUBE TAGGING

Foundations

The efficiency of a hammer depends upon a satisfactory foundation, and this matter should be given careful consideration before installation. Makers recommend a suitable foundation for ordinary good ground, a typical arrangement being shown by Fig. 13. "Good" ground is such as will bear a load of 1½ tons per square foot. If the ground available does not come up to this specification, the depth and area of concrete should be increased, and in bad

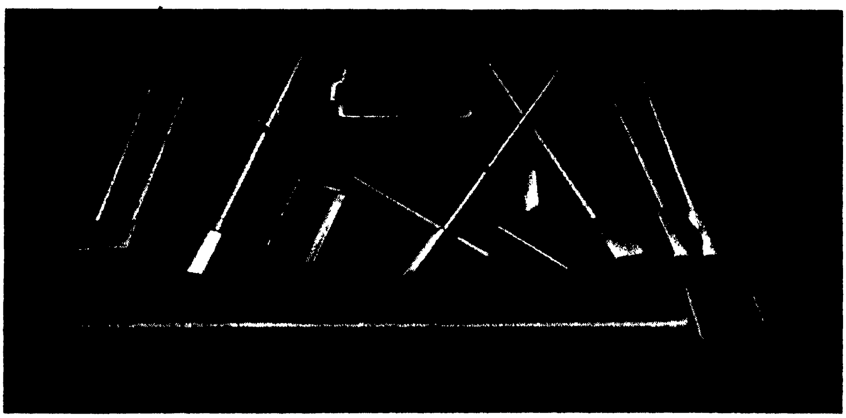


FIG. 12.—SAMPLE TOOLS AS USED UNDER STEAM AND PNEUMATIC HAMMERS

(Left to right) Spring swage, necking tool, ring for holding single swage, V-tool, hot cutter, cold cutter, nobbler or flatting tool, spring necking tool, single top swage; *(bottom)* single swage. *(B. & S. Massey, Ltd.)*

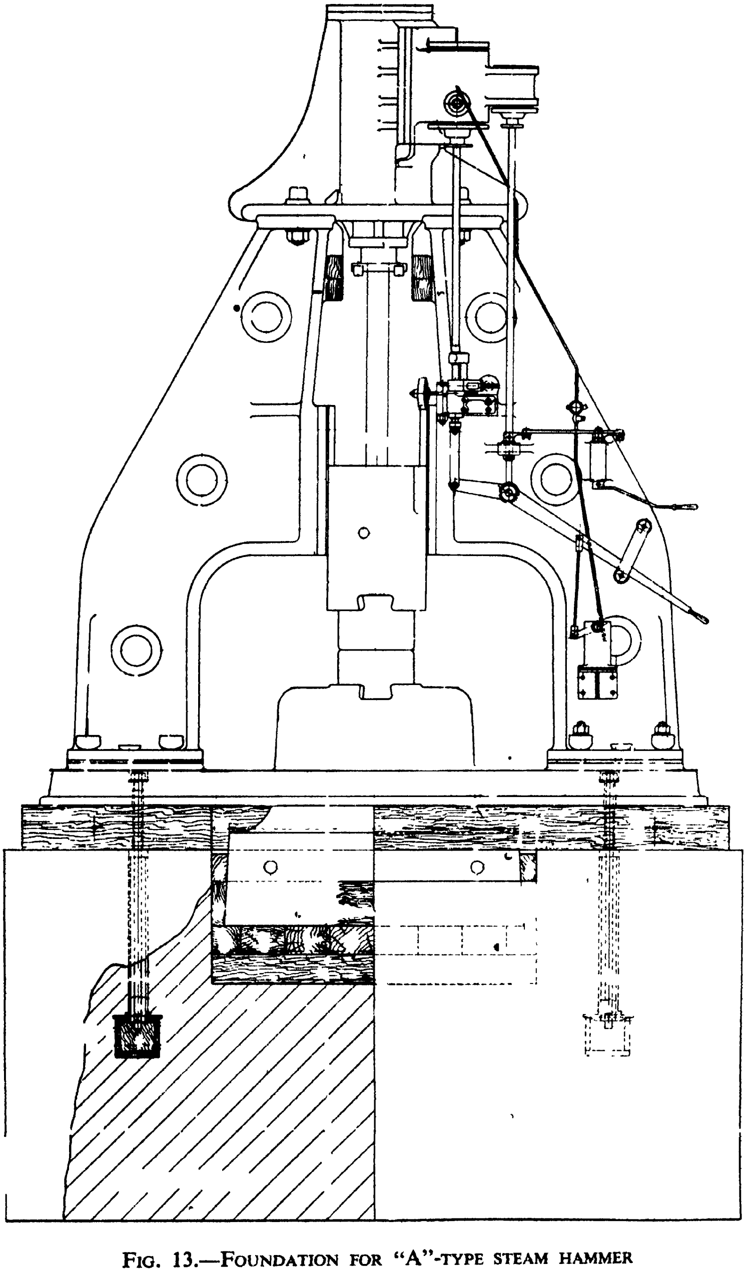


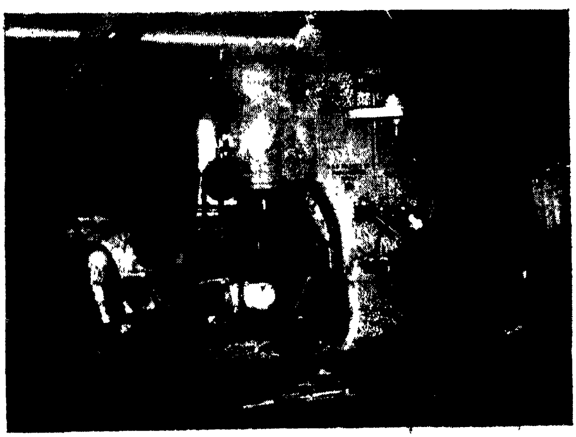
FIG. 13.—FOUNDATION FOR "A"-TYPE STEAM HAMMER

FIG. 14.—2,250-TON HYDRAULIC FORGING PRESS
(Davy & United Engineering Co., Ltd.)

conditions resort must be had to piling. A 20-cwt. hammer should have not less than 4 ft. of concrete under the anvil block. Timber is usually employed between the anvil block and concrete to form a cushion which both protects the face of the concrete and also softens the effect of the blow on the hammer. If the anvil block is too heavy and the foundation too solid, there is a great danger of crystallisation leading to early fracture of the piston rod.

Even with the foundation satisfactory from the point of view of the hammer, vibration may be carried a considerable distance through the ground. If this vibration is likely to be objectionable, a special foundation must be designed. The transmission of vibration can be very considerably reduced by the use of special pads of cork or other material under the normal foundation concrete;

FIG. 15.—SMITH USING PORTER-BAR, WITH HORNS
(B. & S. Massey, Ltd.)



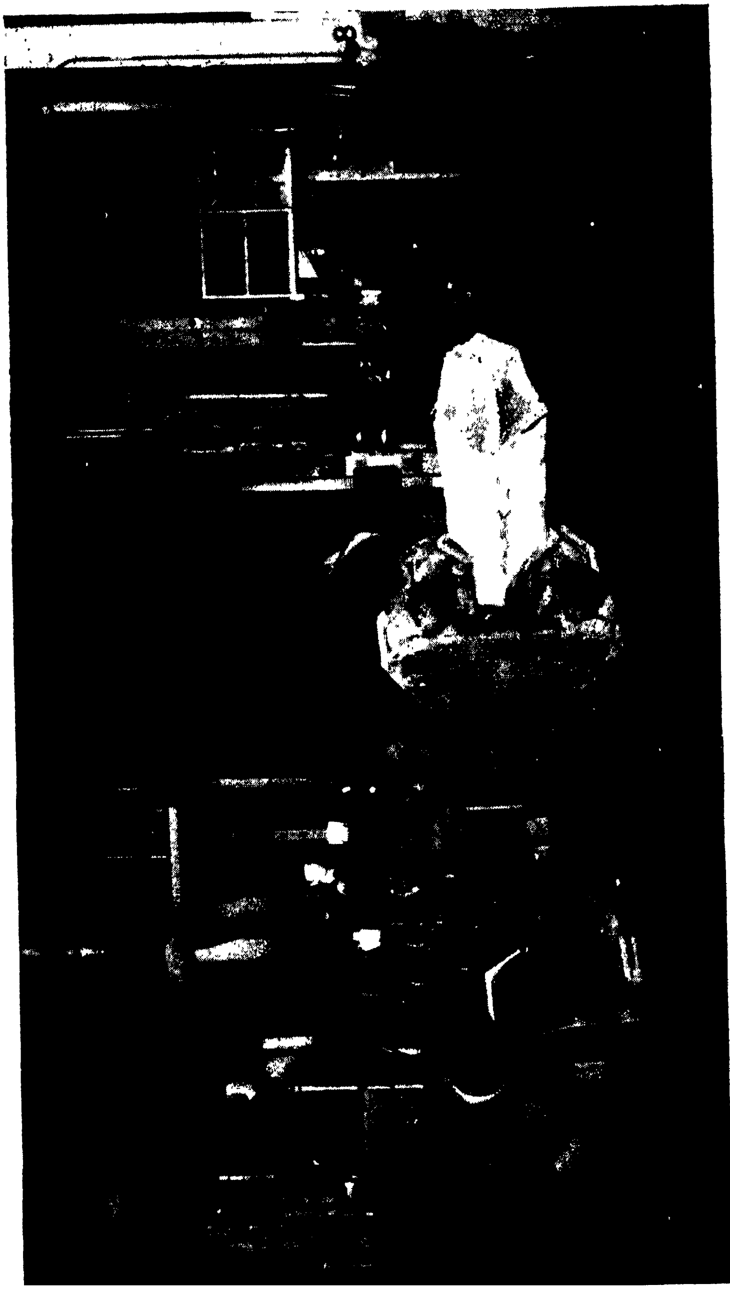


FIG. 16.—ELECTRICALLY DRIVEN MANIPULATOR FOR HANDLING HEAVY FORGINGS
(*Wellman Smith Owen Engineering Corp., Ltd.*)

or this concrete may be suspended on springs. In both these arrangements an additional concrete pit is required, surrounding the normal concrete block. While this adds to the cost of the foundation, the result is very satisfactory.

Hydraulic Forging Press

As mentioned above, the largest forgings necessitate the use of an hydraulic forging press. Fig. 14 shows a typical press, of 2,250 tons capacity, direct pump driven. Such machines have been made up to 16,000 tons, which is more than adequate for dealing with the heaviest ingots normally cast, that may weigh up to about 250 tons. It will be seen that the moving crosshead is guided, not only by the four pillars, but also by the central "stalk" between the two main cylinders. In the earlier presses the necessary speed of working was obtained by a steam hydraulic intensifier system, and this is still thought to give the most rapid and flexible drive. Where steam is not available, however, or is too expensive, electrically driven pumps can now be arranged either delivering direct into the cylinders, or with air-loaded accumulator. On a 6,000-ton press a speed of 50 short finishing strokes per minute is attainable with perfect control.

Manipulators

It is now generally accepted that for handling heavy forgings efficiently a manipulator is necessary. The material used under hammers of say 10-cwt. size and less can usually be handled fairly readily by the smith himself, using ordinary tongs shaped to fit the material. For larger work a "porter-bar" is used, with clamps for holding the material, and "horns" (i.e. four handles projecting at right angles) to facilitate turning. This arrangement will be seen in Fig. 15. A crane is, of course, used for lifting, and is provided with a special turning gear, which can be electrically operated if desired. Even so, however, a lot of man-handling is required, which is not only heavy physical labour, but also slows down the forging work considerably. A mechanical manipulator, as shown by Fig. 16, enables one driver to do the work of four or six labourers and in much less time. Being mobile, it can remove the work from the furnace as well as present it to the hammer or press.

Maintenance of Plant

Since all forging plant has necessarily to work under adverse conditions—heat, dirt, and intense vibration—it is important that provision should be made for really adequate maintenance. Some hints on the upkeep of hammers will be found in a separate section in Volume IV.

Acknowledgments are due to Messrs. Davy and United Engineering Co., Ltd., for permission to use the photograph (Fig. 14) of their hydraulic press, to Messrs. Wellman Smith Owen Engineering Corporation, Ltd., for the illustration (Fig. 16) of their manipulator, to Eumuco (England), Ltd., for the picture of their pneumatic hammer (Fig. 7), and to Messrs. B. & S. Massey, Ltd., for the remaining illustrations.

D. L. P.

DROP-FORGING

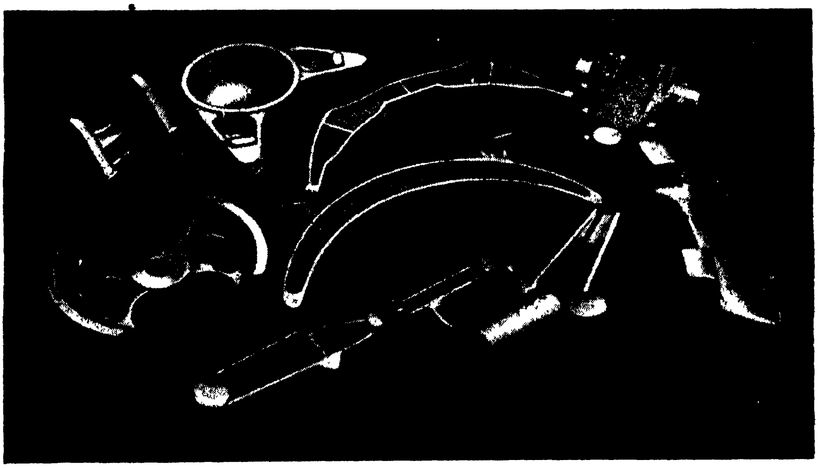


FIG. 1.—GROUP OF LIGHT-ALLOY DROP FORGINGS
Made under a 40-cwt. drop hammer.
(*B. & S. Massey, Ltd.*)

DROP forging may be defined as the practice of forming plastic metal into a specific shape by forcing it, as the result of a blow or squeeze, to fill impressions cut in the faces of opposing dies. It differs from casting in that the metal is not molten or liquid; and from ordinary hammer forging in that the metal is totally enclosed in the dies except for the excess, or fin, which is later removed. It has the advantages that:

(1) The article is produced in large numbers of identical shape and size.

(2) It is quick and therefore comparatively cheap.

(3) The article produced is both lighter and stronger than a similar article produced by any other method.

The Use of Drop Forgings

Wherever a component is required in large quantities and to withstand heavy stresses, a drop forging must be considered. If the material is steel, the work done on the plastic metal breaks up the crystals and generally consolidates the structure. In all cases the drop forging has a homogeneous structure which

can hardly be obtained in a casting, the grain flow can be controlled, and the waste due to machining is reduced to a minimum.

Drop forging originated with the demand of the small-arms trade for large numbers of identical, impact-resistant components. Other industries followed suit, and the requirements of the automobile and aircraft manufacturers finally brought the process to its present position of primary importance.

Typical examples of articles for which drop forgings, either in steel or light alloys, are now used as a matter of course are: spanners, pliers, surgical instruments, needles, cutlery, bossed levers of all sorts, flanges, hooks, brackets, golf clubs. Also manufactured by this process are valves and all those components used in bicycle, motor-car and aeroplane manufacture, such as pedal cranks, freewheel parts, gear-wheels, axles, pinions, crown wheels, hubs, rocker arms, crankshafts, camshafts, connecting rods, engine crankcases, and even propellor blades and turbine blades.

Modern methods of machining allow many articles to be made from the solid comparatively cheaply, but if the material is expensive, as with light alloys or the latest alloy steels, the cost of metal cut to waste becomes an important factor.

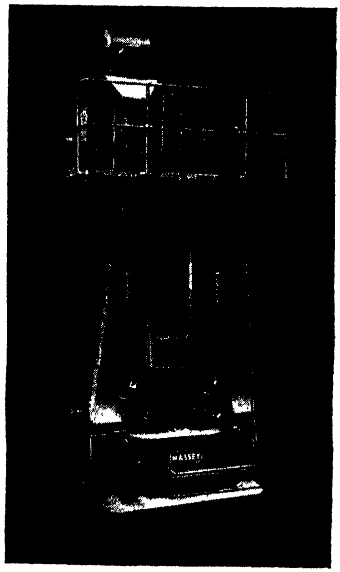


FIG. 2.—20-CWT. FRICTION DROP HAMMER

Self-contained form, with automatic control, operated by foot lever. Will strike light or heavy blows according to angle of foot-board when depressed. Poppets for adjusting lower die.

(*B. & S. Massey, Ltd.*)

In many components it is essential, if maximum strength is to be obtained, that the grain flow should be uninterrupted and in the right direction. Care in the design of the dies and in the method of production secures this result with a drop forging, where it is impossible by any other method. A gear blank is a typical case in point.

THE BASIC PRINCIPLES

A study of the flow of metal during forging shows that, as might be expected, it tends to take the line of least resistance. It therefore soon begins to escape along the parting line between the dies, where it is not restricted, and forms a fin or "flash." At the moment of impact this fin is held by the frictional grip of the dies, and as it becomes thinner it also cools rapidly, so that eventually flow is impeded and the metal is forced to fill up all the spaces in the die. It will be seen, however, that the formation of a fin is essential, and this has to be

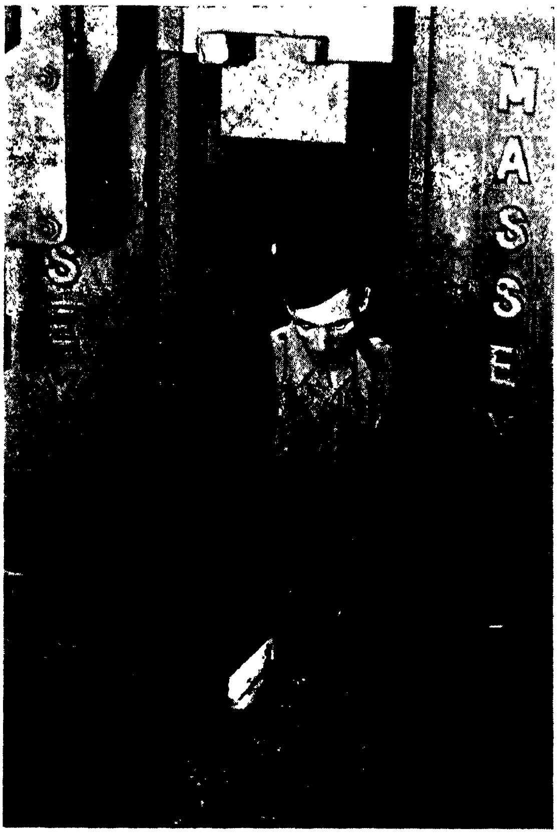


FIG. 3.—FORGING FROM THE BAR

Fullering and edging impressions in die.
(*B. & S. Massey, Ltd.*)

taken into account in designing the dies and in settling the amount of metal required to make the forging.

Drop forgings are made: (*a*) direct from the bar; (*b*) from pieces previously cut to size; or (*c*) from preformed uses, often made with a "tag" which the operator can hold in his tongs. It is a very great advantage for the piece to be held during forging, so that it may be eased out of the bottom die between blows, thus preventing overheating of the die and allowing scale and dirt to be removed.

The Use of Impressions

Preforming can be achieved, even when working from the bar, by including in the dies a number of impressions of various designs, all of which, however, fall into four main categories, namely: (1) fullers, which reduce the section of the stock at the required points; (2) edgers, which, by containing the metal back and front (or even on all sides), gather it together and increase the section at one point; (3) benders, which bend the stock so that it fits the finishing impression; and (4) blocking impressions, which form the metal very approximately to the shape of the finished article, but with all obstructing pattern omitted.

The advantage of blocking is obvious if the case of a flywheel with thin web and heavy rim is considered. If forged from the solid the metal would flow over the edge of the rim, curl back on itself, and finally form a "cold shut."

It has been observed that metal flows more easily into the top die than the

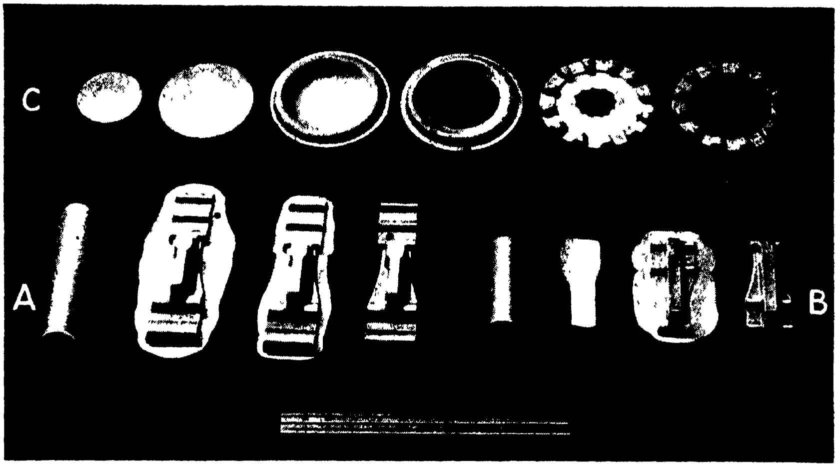


FIG. 4.—FORGINGS MADE FROM CUT-OFF PIECES

A. Trimmed after initial forging and restamped.
B. Forged down first at one end, on side of die, and then finish forged.
C. Initial disc first flattened, then blocked and trimmed, and finally forged in finishing impression.

(*B. & S. Massey, Ltd.*)

bottom, probably because the latter, being in more continuous contact, cools the hot metal more. Deep impressions are therefore arranged in the top die.

Grain Flow

In the case of steel forgings the grain flow should be arranged so as to offer the maximum resistance to the service stresses. Crankshafts should have the grain arranged to follow the bend of the crank; gearwheel blanks should be upended to make the fibres, as far as possible, radial; and hooks should be bent. The design of the dies and the method of production must be arranged to secure these ends.

Keeping Forgings Clean

If clean forgings are to be produced, the scale formed in heating by the chemical action of the free carbon on the hot metal must be removed. Preforming at the same heat helps to do this, but an air-blast should always be arranged to blow on to the bottom die, so that when the forging is lifted the scale is dispersed. Oil or wet sawdust thrown on to the forging as the blow is struck also helps by its explosive action; but modern opinion seems to be against die lubrication, and oil should be used sparingly.

FIG. 5.—FORGING MADE FROM A USE

From left to right are shown the cut-off slug, the same bent to shape, the two ends drawn down, the stamped use, the finished stamping, the fin, and the completed stub-axle forging.

Excess Metal Removal

After forging, the excess metal is removed, usually in a trimming press. Large forgings are trimmed hot, and as they tend to distort in trimming, they are then returned to the dies for "tapping up." This naturally slows down production, and cold trimming is therefore advisable wherever possible.

THE PLANT USED

For the sake of brevity the following sections are arranged in a summarised form:

Drop Hammers

Nominal size indicates weight of falling parts, exclusive of top die. Made in two types:

(1) Gravity fall:

(*a*) Board drop, in which tup is secured to a board lifted by opposing cam-operated rollers. Action purely automatic, controlled by foot lever. Maximum size about 40 cwt., maximum stroke about 4 ft.

(*b*) Friction drop, in which tup is secured by belt or ropes to rotating arm operated by friction clutch of band-brake type, usually water-cooled. No limit of size. Controlled in larger sizes by hand pulling cord, in smaller sizes either by hand or automatic, with foot operation. Normal stroke about $5\frac{1}{2}$ ft. in self-contained form or 7 ft. in battery form.

(2) Steam (or compressed-air) double-acting stamps, also known as steam drop hammers. Lifted by pressure under piston, and force of blow increased by pressure above piston. Stroke about 3–4 ft. Speed considerably higher than gravity fall, but running costs also higher. Will give short-stroke, light blows very rapidly.

FIG. 6.—50-CWT. FRICTION DROP HAMMER
Battery form, with rigid guides.
(*B. & S. Massey, Ltd.*)

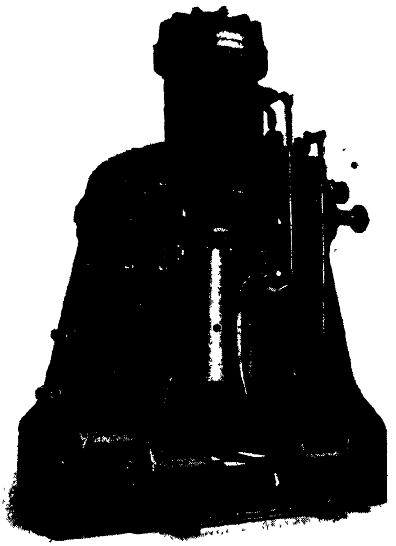


FIG. 7.—40-CWT. STEAM DROP HAMMER, RAM TYPE

Also known as a double-acting steam stamp. Note large-diameter hollow ram forged solid with tup, instead of conventional piston rod. (*B. & S. Massey, Ltd.*)

Forging Presses

These machines, which work on an eccentric, complete in one stroke a job which may take a drop hammer ten or more blows. Therefore they are necessarily immensely strong and rigid, and correspondingly costly. Presses are built up to 6,000 tons pressure, and are most suitable for long runs because of their high output.

Forging Machines

Horizontal, used mostly for forgings of circular shape produced from the bar. By using a bar very little material will be lost. All these machines are provided with split dies, which will clamp the bar, holding it in position, and then the header punch will form the bar to its proper shape. At the end of the stroke the split dies will open and the bar can be withdrawn easily. Machines can be provided with a fabricated frame or with a cast-steel frame. Numerous safety devices are employed to avoid overloading. Very high output, but dies expensive, and considerable experience required in processing and designing dies.

Friction Screw Presses

Action midway between press and hammer. Used extensively for hot brass forging, but also for other purposes.

Trimming Presses

For removing the fin or flash. Crank-operated. Larger sizes geared. Modern machines push-button operated.

Pneumatic Power Hammers

Very useful for drawing out before or after drop forging, and for preparing "uses." Electrically operated. Sizes up to 40 cwt.

Helve Hammers

Also used for drawing out, especially on small forgings. Very fast, light blows. Can be used for sizing round forgings by rolling during forging.

Counter-blow Hammers

These hammers eliminate the use of anvil blocks. They have two tups, an upper and a lower one. The upper tup is connected with a piston rod and piston, which moves in a cylinder fixed above the standards, and according to the medium being above or below the piston, the tup will move up or down. The driving medium can be either steam or air. The lower tup is mechanically coupled to the upper tup and thus follows its movements. This means that the whole energy of the moving tups is taken up in the forging itself. One advantage of this type of hammer is that it can be used on ordinary foundations.

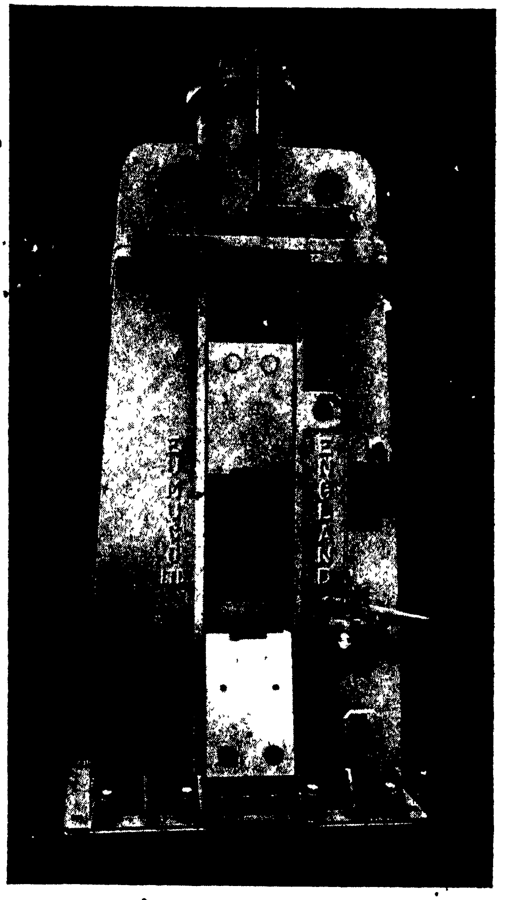


FIG. 8.—13-TON COUNTERBLOW HAMMER (*Eumuco* (*England*), *Ltd.*)

Rotary Swaging Machines

These machines are used where a reduction has to be made in the diameter of shafts or tubes. They can be provided with pneumatically operated clamping and feeding devices to facilitate handling of the component.

Gap Rolls

These machines are used for drawing and flattening, chiefly in the manufacture of agricultural implements and also in numerous other industries. Up to six passes may be used according to the shape of the part. Electrically operated. Rotating half-cylindrical rolls grip work and roll out towards operator.

Coining Presses

Very sturdy, mechanically operated machines used for sizing forgings and where it is necessary to reduce or avoid machining allowance. Generally, operations are carried out in a cold state. Only required for work to a very exacting specification.

DIES

Below we give the recommended specifications and heat treatment of the steel to be used for large and small dies respectively.

LARGE DIES.—(*a*) Carbon, 0·45–0·50%; silicon, 0·30% maximum; manganese, 0·50–0·80%; sulphur, 0·05% maximum; phosphorus, 0·05% maximum. Normalise at 830° C. and cool in still air. If impressions are shallow, face may be hardened, but it is difficult to prevent warping.

(*b*) B.S.S. No. 224, Type 1: carbon, 0·55–0·65%; silicon, 0·30% maximum; manganese, 0·50–0·80%; sulphur, 0·05% maximum; phosphorus, 0·05% maximum. Normalise at 825° C. and cool in still air.

(*c*) B.S.S. No. 224, Type 2: carbon 0·55–0·65%; silicon, 0·30% maximum; manganese, 0·50–0·80%; sulphur, 0·05% maximum; phosphorus, 0·05% maximum; nickel, 1·00–1·50%; chromium, 0·30% maximum. Normalise at 825° C. and cool in still air. Oil-toughen after cutting impression.

SMALLER DIES.—(*d*) B.S.S. No. 224, Type 3: analysis as (*c*), but nickel, 1·25–1·75%; chromium, 0·50–0·80%; molybdenum, 0·20–0·30%. Soften at 630° C. for ease in machining face, and dovetail. Harden at 820° C. and temper at 600° C. before sinking.

(*e*) B.S.S. No. 224, Type 4: carbon, 0·30–0·36%; silicon, 0·30% maximum; manganese, 0·40–0·70%; sulphur, 0·05% maximum; phosphorus, 0·05% maximum; nickel 3·00–3·60%; chromium, 0·60–1·00%. Oil-harden at 830° C. and temper if required.

Choice of material is determined by the number of stampings to be made, the steel specified, the design, and the facilities available for heat treatment of the dies. Certain firms specialise in the manufacture of die blocks, and may be relied on for excellent products and good advice.

Sinking

Mark out carefully from locating edges, allowing for contraction. "Draft" varies from 3° on shallow impressions to 7° on deep recesses. Profile and depth templates are usually employed. Round impressions can be finished in a lathe. Other impressions can be milled or a special die-sinking machine may be used. In large plants, automatic machines reproduce from a master die. Finishing is done by hand with grinding tools, scrapers, and the like. Good finish is an asset, and makes for longer life. Lead casts are taken for proofing purposes.

Design

The design settles the method of production. The centre of work done, not necessarily the centre of forging, should be on the centre line of hammer. In multiple-impression dies, keep heavy work near the centre, usually the finishing impression. When working from bar, provide a "gate." The finishing impression may be surrounded by a "trough" or "gutter" to facilitate flow of the fin. Stepped dies, i.e. dies in which the joint line is not horizontal, must be

balanced or "locked" by an opposite step. Sometimes a second impression can be used for the same purpose.

Spigot and recess in die faces outside impressions can be used for locating. Similarly, meeting or "rapping" faces on dies ensure accurate sizing by fixing fin thickness. Deep impressions should be arranged in the top die. Flow of metal must be considered to avoid "laps" and "cold shuts" caused by metal flowing back on itself, and additional blocking impressions help in awkward cases. Direction of fibre is important, for instance in upending for gear blanks.

Dies for horizontal forging machines and vertical forging presses require very special consideration.

Trimming Tools

The bottom tool must be sufficiently rigid to bridge supports without "give." The top tool must fit cleanly on to the forging to prevent distortion, particularly when trimming hot. Cold trimming is preferable wherever possible, and provision is required for the forging to fall through and be removed. The bottom tool should have a parallel cutting edge of about ¼ in., and then be "backed off" to give a clearance. Normally, the top tool should be a good fit in the bottom tool.

HEATING AND HEAT TREATMENT

Furnaces for non-ferrous metals require special consideration, and cannot be dealt with here. Straight and alloy steels may require heating up to 2,400° F., say 1,310° C. "Batch" furnaces are filled and emptied or may have new stock inserted piecemeal as the heated stock is removed. Continuous furnaces feed automatically—pusher type by electric drive, gravity type for round stock by means of sloping bottom to furnace, rotary type by revolving floor. The design depends on the particular requirements. It is often advisable to use two batch furnaces to one drop hammer. The fuels may be oil, gas or coal. Oil gives quickest heat, gas is cleaner and more easily controlled. Automatic temperature control is a great advantage.

The aim should be a steady supply of material, well soaked and just reaching correct temperature ready to be taken from the furnace as required by the drop forger. Scale is formed on the steel in heating as the result of a chemical action between the free oxygen in the furnace and the heated metal. Excessive scale is the result of incorrect control. Overheating results in burning, high carbon steels burning at a lower temperature. Electric induction-heating furnaces avoid the formation of scale, but are very costly to install and run.

Most drop-forging specifications now demand heat treatment after forging to ensure correct properties. The treatment, usually specified, depends on the type of steel, and is generally either normalising, annealing, oil or water quenching, tempering.

NORMALISING.—This process comprises heating just above the critical temperature (about 850° C. for mild steel) and allowing to cool in air. It refines the structure and corrects the results of hot working and irregular cooling.

ANNEALING.—As above, but the cooling is carried out very slowly. The softest possible condition for machining is achieved by this process.

QUENCHING.—When quenching, the steel is heated above the critical temperature and immersed in oil for toughness, or water for hardness. It retains the permanently fine structure induced by heating above the critical temperature, but considerable strains are caused which must be relieved by tempering. Alloy steels are rarely quenched in water.

TEMPERING.—The steel is reheated after hardening to a temperature below the critical point, and allowed to cool. This procedure relieves stresses, toughens the material, and makes it less brittle.

FINISHING.—It is generally necessary to clean forgings to remove dirt and scale caused in heat treatment. There are three main methods—pickling by immersion in an acid bath; tumbling by rotating in a barrel with abrasive and small bits of scrap metal; sand or shot blasting by propelling shot or grit at high velocity, by air pressure, or centrifugal force, on to forgings.

Inaccuracies in trimming and minor surface blemishes and defects are removed by grinding.

INSPECTION AND TESTING

Most drop forgers are content to have chemical tests made for them by some outside agency, but visual inspection of forgings should begin with the first forging made and be carried on continuously. Check hot for offset forgings due to dies not matching, for laps or seams, and for filling of dies completely. Check cold for dimensions and weight. If required, samples must be prepared for physical tests. In some cases every forging must be tested in jigs for particular dimensions.

HANDLING AND MAINTENANCE

Anything which relieves the operator of manual labour aids production. High output involves movement through shops of considerable volume of material. Layout should reduce movement to a minimum and aim at continuity progress. No hard-and-fast lines can be laid down—type of handling equipment required depends on circumstances—even a wheelbarrow may be best sometimes. But it must be emphasised that every means should be employed to minimise man-handling.

A special article appearing in Volume IV has been devoted to the subject of maintaining drop-forging equipment, but it may be mentioned here that high output demands really adequate maintenance, as any shut-down period is a direct loss. Sufficient spares must be carried and replacements should be made before, not after, breakdown, and, in this respect, routine examination of plant is essential. The surfaces of anvil blocks, dieholders, and tups must be kept in good order to prevent die movement or breakage.

D. L. P.

WIREDRAWING

THE whole theory of wiredrawing is based on one remarkable property of wire—its capability of being stretched to a great extent before it reaches breaking-point.

Wiredrawing is the term given to the process used in wire manufacture whereby the diameter of the wire is reduced by pulling it through successively smaller holes in a tungsten-carbide die-block. The process can be repeated several times, depending on the material used. A copper wire, for example, 36 in. long and $\frac{1}{4}$ in. diameter, can be elongated by being drawn through successive tapered dies until it is 15,300 times its original length, one yard of wire drawing out into nearly nine miles with a diameter of 0·002 in. Most materials do not, of course, draw out to such an extent before becoming brittle, and before this overdrawn point is reached the material is annealed or softened, after which it is ready for further drawing.

Copper, Bronze, and Brass Wires

When producing copper, bronze, and brass wires, the initial material is first cast in the form of a billet of square section, say, 4 in. $\times$ 4 in., heated in a special furnace, and rolled down several passes to either $\frac{1}{4}$ in. or $\frac{5}{16}$ in. diameter. These are known as rolled rods, and represent the raw material supplied to all wire manufacturers. After cleaning or pickling in sulphuric acid, the scale due to rolling is released, the coils are washed thoroughly under pressure and placed in a wet tub to prevent further oxidation.

Usually the first reductions are accomplished in a tandem machine (see Fig. 1). This consists of a number of revolving drums or capstans, each rotating at an increased speed according to the elongation of the wire. If, for example, the wire or rod enters the first die at 100 ft. per minute, it will leave the die at a corresponding rate to the elongation, say, 130 ft. per minute. This must be pulled by the capstan at this rate, and to ensure that this is done the capstan is made to rotate at a slightly higher speed. As the wire leaves the first capstan at a rate of 130 ft. per minute, and enters the following die, this length of wire is again increased by the reduction. At the same rate of reduction the length increases to 169 ft. per minute, and the capstan is designed to accommodate this new increase by being driven at a speed in excess of the wire speed. This procedure is carried out systematically throughout the machine, and eventually we find the $\frac{1}{4}$-in. wire entering the machine at a speed of 195 ft. per minute, whilst through nine reductions a smaller wire of 0·064 in. diameter is being produced at 3,000 ft. per minute.

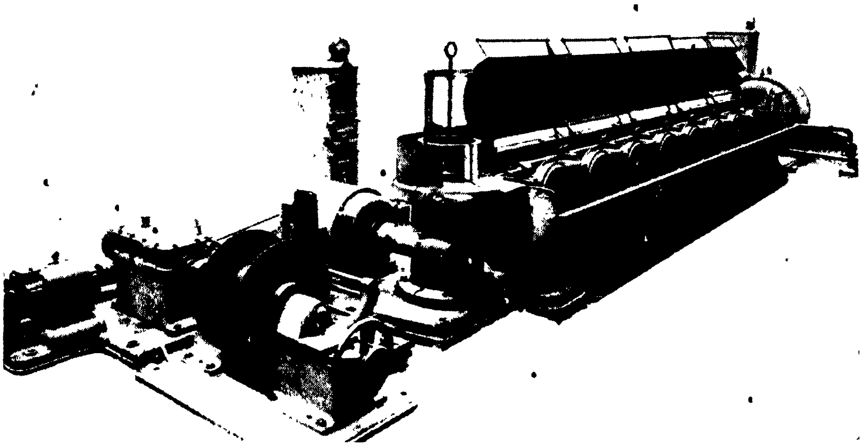


FIG. 1.—A NINE-DIE TANDEM MACHINE USED FOR NON-FERROUS METALS

To collect this wire, the block or spool is necessary. A block is really a very ingenious method of coiling wire, the wire being pulled through the final die at the base, the base of the block being slightly tapered to allow each successive lap to displace the previous lap by pushing it up the taper. If wound direct on to a spool the wire must be wound at a constant lineal speed, but the revolution of the bobbin decreases in speed as the bobbin or spool begins to fill. Various methods are employed to obtain this continual decrease of spool speed: differential gearing, friction clutches, fluid flywheels, automatic alteration of cone drives, magnetic devices, variable-speed mechanisms—all designed to change the spool revolutions automatically without stretching or influencing the finished wire.

For finer wires the drawing capstans are arranged in the form of a cone as shown in Fig. 2. To draw successfully at high speeds, the wire cones and dies must be adequately lubricated, and in the machine in question this is accomplished ingeniously by submerging the whole of the drawing operation, the cones being turned into the horizontal position when threading the machine. Speeds of 4,000 to 5,000 ft. per minute are obtainable on a machine of this type, wires being welded at the input end, making the operation practically continuous except for the time necessary to change spools or collect the finished coils.

Non-ferrous Metal Wires

Non-ferrous metals are usually drawn on the type of machine shown in Fig. 2, smaller models being designed for production of wires below four-thousandths of an inch in diameter down to the finest size of one-thousandth. There are, however, alternative designs, the principle of which is based on "non-slip" lines. Such a machine is shown in Fig. 3, and in this case each drawing block

and die can be water-cooled. The input wire is drawn through the first die and coiled on the block at a definite speed. No slip is possible, due to the coil-friction of wire. The principle involved is that a certain amount is drawn on the block, but a slightly less amount is taken off at the same time by the overhead arrangement. This means that all the blocks are accumulating a stock of wire continually, and can efficiently feed the following blocks. If the accumulation eventually becomes excessive, any block can be stopped by an operator, and this automatically stops all previous blocks, leaving the remaining blocks to continue production.

Iron and Steel Wires

The preparation of mild steel and high carbon steel wires is similar to non-ferrous, except the wire has to be prepared with a suitable coat for drawing. This is usually ferric oxide, formed by allowing the wire, after cleaning in hydrochloric or hot sulphuric acid, to oxidise whilst under the action of a wet spray. To neutralise the acid the coils are dipped in hot lime and baked in an oven to draw off occluded hydrogen. They are then ready for drawing, each reduction being drawn through an olive-oil soap lubricant. Special wires such as furniture springs, mattress wires, and wires with a high surface finish are drawn wet, but by far the largest proportion are drawn by the "dry-lubricant" process.

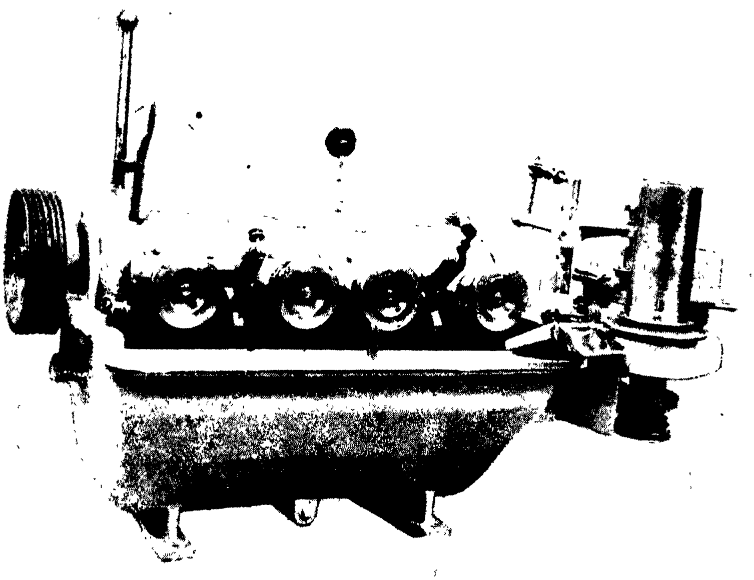
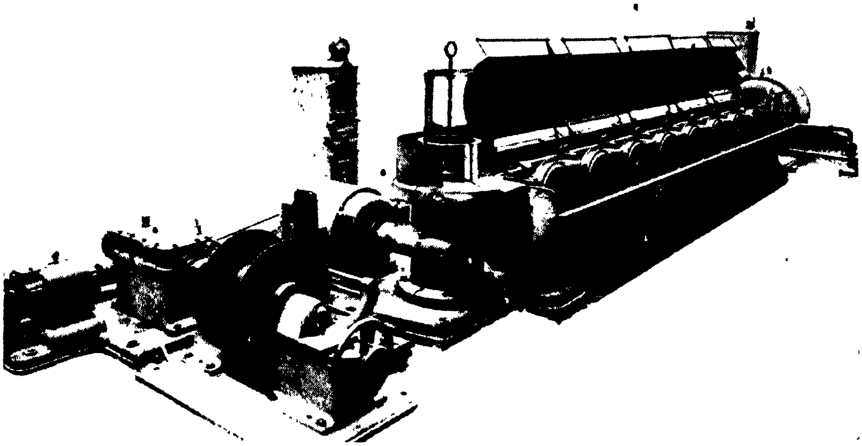


FIG. 2.—MACHINE FOR DRAWING FINE WIRES
The drawing capstans are arranged in the form of stepped cones.



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minute, but unfortunately the question of preparing the wire for drawing, the lubrication during reduction, the profile of the die, and the cooling of the machine parts has not kept pace with the improvements in the machine itself.

Speed Control

By use of direct-current motors and suitable regulating controls it is possible to regulate automatically each drawing capstan to suit the elongation of the wire at each reduction, but the capital cost of such a machine is necessarily high and many attempts are being made at the moment to produce the same results by using alternating current in combination with magnetic clutches. Every device known to the engineer has been tried out, fluid flywheel couplings, mechanical variable couplings, hydraulic couplings, friction clutches, coil clutches, plate clutches, and similar mechanical devices to control speed. Fig. 4 shows the machine equipped with automatic direct-current control. Other machines are operated by alternating current in conjunction with magnetic couplings. Whatever device is used, the same purpose is achieved, this being to regulate the speed of the drawing cones to a speed equal to the speed of the wire at each reduction, and so produce wire without any slip between the wire and capstan.

Because the demand for wire in every size and every quality is so great, more progress has been made during the past fifteen years than in the previous three hundred. As facilities for handling are improved, the demand for longer lengths increases. To feed galvanising machines, nail-making machines, netting weaving, reinforced-fabric, bolt-straightening, cable and stranding machinery,

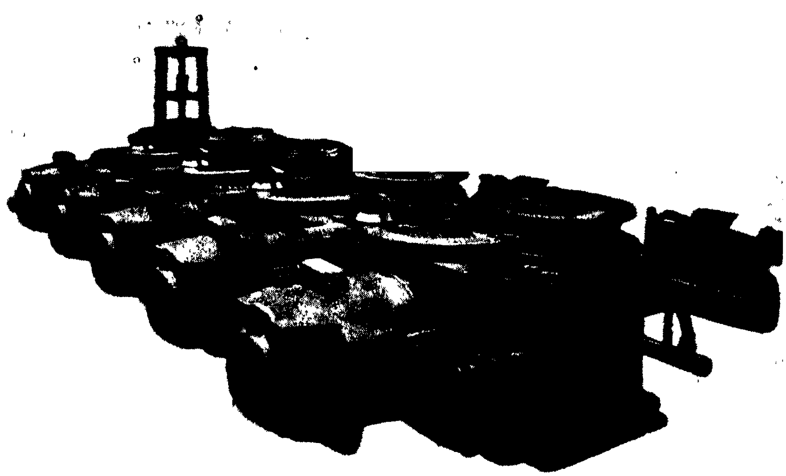

FIG. 4.—MACHINE FOR THE PRODUCTION OF LARGE WIRES WITH AUTOMATICALLY CONTROLLED D.C. MOTORS

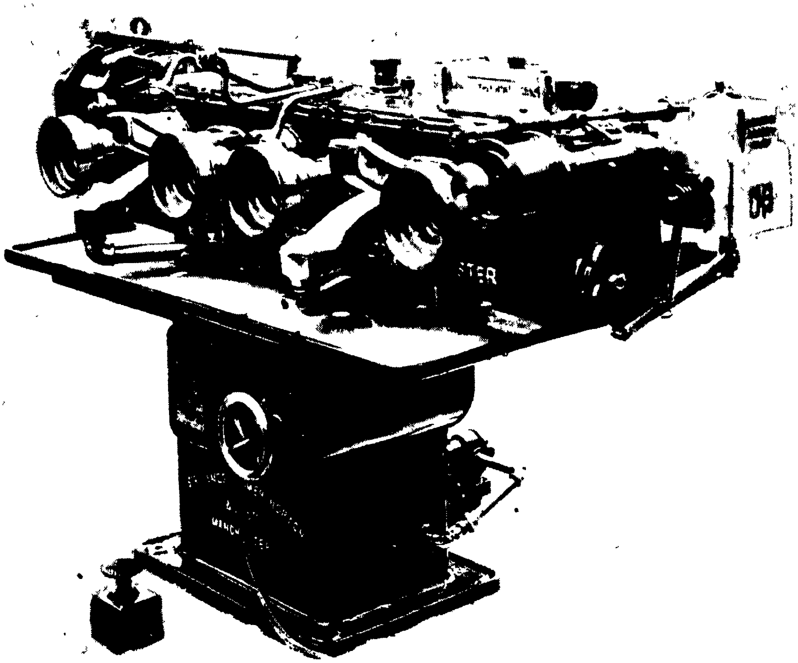

FIG. 5.—WET-DRAWING MACHINERY FOR WIRES AS FINE AS $\frac{1}{1000}$ IN.

the demand is for larger coils or wire wound on to spools. The latter is a fascinating problem: as the wire is drawn at a constant speed, to obtain a constant specification it has to be wound on to a spool, the revolutions of which have to alter after each layer is completed. As the layers increase the revolutions decrease in proportion, a very difficult problem when wires of $\frac{1}{1000}$ in. diameter are under consideration. It is accomplished very successfully by introducing in the mechanism driving the spool some form of slipping device such as a friction clutch, magnetic clutch, fluid coupling, thermionic valve control, or variable-speed gear which is altered mechanically, at each traverse of the wire across the spool.

Cold or Hot Drawing ?

Several experiments are being carried out to prove whether wire can be drawn by other methods than by reducing it by cold drawing. Machines are in operation to see if satisfactory results are obtainable by hot drawing.

Better quality wire is claimed by "scraping" the first reduction, thereby removing from the rod all the impurities caused by the rolling operation. In some wires, for example zinc wire, the grain structure is too coarse to elongate

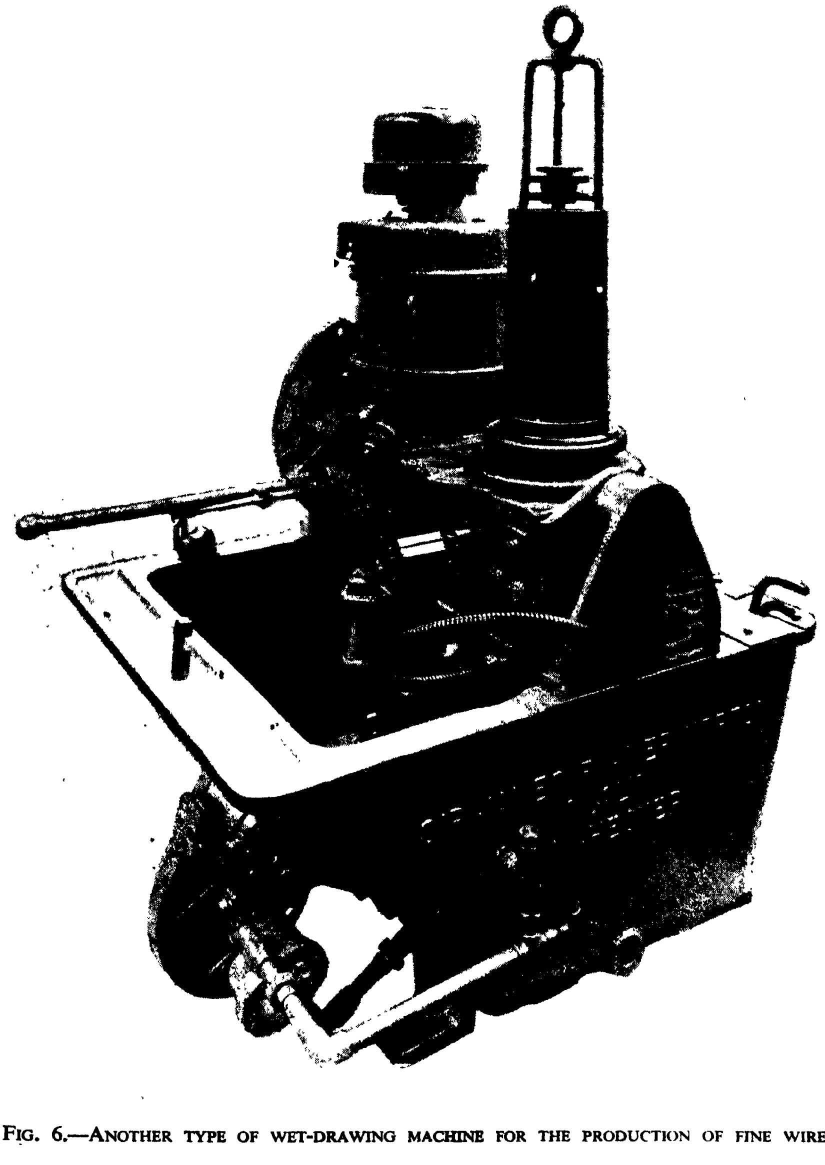

FIG. 6.—ANOTHER TYPE OF WET-DRAWING MACHINE FOR THE PRODUCTION OF FINE WIRES

into wire and the grain has to be altered by rolling the wire into a suitable condition for drawing.

Rotary Swaging Process

Tungsten wire is continually hammered by a rotary swaging process and then drawn by the hot-drawing method. Different metals need different treatments to obtain specific strains, elongations, and torsions. The art of the responsible wiredrawing authority is to know exactly which operation to perform at the right moment, using whatever machines he has at his disposal. So much depends on his craftsmanship that suspension bridges, mining ropes, ships ropes, cables, aeroplanes, and motor-cars are all being vitally affected by the quality of the wire produced.

Resetting the Dies

The art of wiredrawing demands a great deal of skill and experience, but recent developments in machine design have done much to lessen the peculiar difficulties of the machine operator. Only a few years ago it was exceedingly difficult to produce a large coil of wire the same size at each end, due to the fact that the wire had, of necessity, to be drawn through hardened-steel plates. The hole enlarged eventually, and had to be battered and reset by the operator, the art of resetting being the main skill of the wiredrawer. The invention of synthetic dies changed this, and nowadays an operator is given a set of dies which will draw many tons of wire before being opened to the next size. In consequence, it was found that higher speeds were possible, and with facilities for cooling the wire and dies at every reduction, the operation of producing wire became practically semi-skilled.

The Pointing Machine

To operate a particular machine the process is always the same. The wire to be reduced has to be pointed sufficiently to pass through the reducing die. This is accomplished by a pointing machine, which is simply a pair of small rolls, power driven. The rolls have a special set of grooves, sometimes designed as an eccentric groove. As the rolls slowly revolve, the wire to be reduced is pushed into the rolls and the point automatically produced by pressure. Alternative methods are to reduce the wire by swaging the end on a rotary swaging machine or to place the end of the wire between two electrodes, heat it to a definite temperature, and elongate it automatically when this temperature has been attained. The result is that the hot wire is stretched until it breaks, leaving a point on each wire sufficient to enter the die.

The Wire-threading Operation

The next procedure is to push the pointed wire through the die, grip the pointed end by means of a pair of jaws attached to the capstan or drawing block, set the machine in motion, the wire being drawn on to the block, each

successive turn on the block causing the previous turn to rise. The wire drawn accumulates on the block, the end is repointed to suit the next reduction, and by repeating the process the wire is eventually threaded on all blocks.

All that remains is to set the machine in motion and draw either on to a finishing block or spool as desired. Stripping the finished coil is a simple matter with the use of collapsible strippers. A stripper or framework, usually collapsible, is inserted on the finishing block. When the finished coil is complete, the stripper and wire are withdrawn, and, by releasing a spring clip, the finished coil is deposited where desired.

For tandem-type machines an auxiliary machine, specially designed to thread nine dies simultaneously, is used, saving valuable time in threading.

Automatic Machine Control

It is not essential for the operator to pay continuous attention to his machine, as automatic devices are provided to stop the machine should the wire break. This device is arranged to stop a particular drawing block and all preceding blocks, allowing the finishing block to continue production. Now that the welding of rods has become an everyday operation, it is not surprising that efficiencies of over 90 per cent. of the theoretical speed are quite easily obtainable. This concentration on the mechanical equipment, making wiredrawing almost automatic, has resulted in operators being capable of supervising the output of several machines, with consequent reduction of costs and increased remuneration for their labours.

Maintenance

Since a wiredrawing machine is not very complicated, it depends largely on its robustness to undertake the work required. Very little maintenance is needed, as the gearing used is invariably totally immersed in an oil bath. From time to time roller bearings and ball bearings require replacement, but this is ordinary maintenance work which should be done to most other machines.

On machines built on the slip principle there is always the question of drawing capstan grooving due to the wire continually slipping on the cones, but by employing material of a nickel-chrome structure, or "fescolising" the cones, this maintenance occurs only once in every few years.

Tungsten-carbide Dies

The secret of performance of modern machinery depends on the success of the die. Tungsten carbide is a synthetic material formed by particles of tungsten carbide and a matrix such as cobalt. By sintering these particles in a suitable electric furnace an exceedingly hard material is produced. It is so hard that it will easily cut glass and is an excellent substitute for the diamond, which is nowadays only used for producing wires below 0·072 and usually below 0·040 diameter.

This tungsten carbide can be pressed into any required shape by inserting it as a powder in a special mould made to suit the shape desired. For single-sintered

work, a graphite mould is necessary, and for double-sintered work a metal mould which can be used more than once is desirable. The moulds are heated to a very high temperature and the powdered carbide and cobalt subjected to high pressure, producing "pellets" of hard tungsten carbide to the shapes desired.

These are then machined to suit requirements by means of diamond-impregnated wheels or lapped into the required shape by steel needles impregnated with boron carbide or diamond dust.

To ensure sufficient support to the carbide, which is capable of withstanding great compressive stresses but has very little tensile strength, the pellet is encased in a steel mount or case. Thus, when the wire is reduced through the die, the case has to withstand enormous pressures.

The maintenance of tungsten-carbide dies is dealt with in an article contained in Volume II of this work.

Die-profile Considerations

The profile of the die has to be a specific shape depending on the quality of wire to be reduced, the type of wire, and the lubricant used. For example, when drawing high-carbon steel with 19 per cent. reduction of area, a die with 11½° angle and 50 per cent. bearing would be considered satisfactory. On mild steel a 14° reduction angle is desirable, and on softer metals, such as copper, a reduction angle of 16° is recommended with the profile somewhat similar to a parabola.

Applications of Tungsten-carbide Dies

These dies are such a revolutionary innovation that they are developed for drawing tubes up to 3 in. diameter and solid shafts to 2½ in. diameter, the tungsten carbide being satisfactory under these tremendous pressures. At the moment dies have been developed as fine as 0·006 in. diameter, but eventually they may supersede the diamond die, since, owing to economic reasons, diamond prices are continaully rising and, due to competition in tungsten carbide, new developments in manufacture have been made with subsequent reduction in prices.

Wire-processing Operations

In this general survey of the factors influencing wiredrawing practice we have not been able to cover the interesting processing such as patenting, annealing, galvanising, hardening, and tempering, all of which are subjects in themselves. Much progress is being made at the present time in the development of new coatings, methods of cleaning and galvanising preparatory to drawing, to meet the continual call for higher speeds of production, but the greatest advance during the past twenty years has been in machine development and tungsten-carbide die manufacture.

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N. D.